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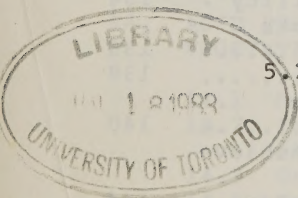


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1. INTRODUCTION

1.1 Objectives of This Submission

On March 27, 1981, The Province of Ontario prepared and presented "An Expanded Submission to the United States Environmental Protection Agency Opposing Relaxation of SO₂ Emission Limits in State Implementation Plans and Urging Enforcement". This document clearly and forcefully presented Ontario's position (backed by factual information and data) with regard to transboundary air pollution and its consequences to the Province. (See Appendix 1.)

Further, on June 19, 1981, representatives of the Ontario Ministry of the Environment, on behalf of the Province, presented scientific and technical evidence on transboundary air pollution to a Hearing Panel of the United States Environmental Protection Agency in Washington, D.C. in the matter of Interstate Pollution Abatement. At those Section 126 Hearings, the Ontario presentation had two main thrusts:

1. To illustrate the effects of transboundary pollution on the New York, Pennsylvania and Ontario regions.
2. To present to EPA a "Case Study" of how a jurisdiction at the State level (Ontario) can control aggregated SO₂ sources in relation to transboundary pollution, and to show how it is possible to use long range transport modelling in the consideration and control process.

A printed version of the evidence presented at the June 19, 1981 Hearings can be found in Appendix 2 of this document. The material contained in this present submission is supplementary and complementary to that evidence.

This presentation will directly address the points outlined in the Federal Register, Volume 46, No. 84, Friday May 1, 1981. In particular, this material will:

1. Illustrate the "regional" as opposed to the "local" nature of the phenomenon of long range transport. In its March Submission, Ontario stressed the point that this Province shared a regional "airshed" with the Northeastern United States and that the most environmentally sensitive part of Ontario is literally wedged, (See Map 1.1), in the middle of a highly industrialized group of states and therefore Ontario's environment must be studied, assessed and protected in close concert with the U.S. Ontario maintains that the airshed of concern here is common to many States and Provinces and that pollution control must be a shared responsibility of all parties of that airshed.
2. Demonstrate that the adequate management of this problem necessitates jointly addressing the issues of:

- (a) aggregate pollutant sources versus single sources.
- (b) multiple versus single pollutants, i.e., no one pollutant such as SO₂, particulate matter or ozone can be considered in isolation and that secondary pollutants such as nitrates and sulphates which are products of long range transport and atmospheric transformation must also be included in this investigation. Ultimately, consideration of the deposition of acidic materials must enter into this complex discussion of source-receptor relationships.

Further, we will outline, using the "Case Study" technique, that it is currently possible to use long range transport models to assist in developing appropriate abatement strategies.

Finally, this document is submitted in the spirit of the announcements in the Federal Register, Volume 46, No. 176, Friday, September 11, 1981 regarding the relevance of additional information in the Section 126 process.

1.2 Organization of This Submission

The organization of the material in this submission is designed to convey a feeling of the scope of the phenomenon and therefore the need for Government Agencies to consider the Long Range Transport of Air Pollutants when attempting to deal with emissions of pollutants, which up to this point have been dealt with, or regulated, for local purposes only.

Beginning with a short summary of the major legal points taken from the Ontario Government's June 19, 1981 presentation, the emphasis shifts to outlining in detail a comprehensive technical case. Emissions are quantified in Chapter 3; then the means by which these emissions are transported vast distances, from the various sources, is established, with reference to specific documented episodes in Chapter 4. Chapter 5 emphatically demonstrates why, by discussing atmospheric chemistry, the historic way of dealing with pollutants on an individual source and individual or "primary" pollutant basis, has aggravated the long range transport of air pollutants phenomenon. This is because secondary pollutants were not considered. Chapter 6 then details the various means by which the primary and very important secondary pollutants are removed from the atmosphere and deposited in the environment. Chapters 7 through 10 deal with the problem of modelling this phenomenon, from source to

receptor, and discuss the Ontario Ministry of the Environment's model, the setting of standards in Ontario and the application of models to assist in the development of a multiple source abatement strategy.

Chapter 11 deals with the financial implications of SO_2/NO_x reductions in U.S. power plants.

Finally the remaining four chapters, Chapters 12 through 15, discuss the effects of primary and secondary pollutants on the environment of Ontario, thus substantiating the need for action at this time.

2. SUMMARY OF LEGAL ASPECTS

On May 28, 1981, Ontario filed with EPA a request "that EPA expand the scope of the Hearings it has announced under Section 126 of the Clean Air Act to include closely related information that is relevant to the Agency's obligations under Section 115 of the Clean Air Act". (See Appendix 2, page 5 of Mr. Scott's Introductory Remarks.)

At the outset of the Hearing on June 18, 1981, EPA announced its determination not to burden the proceeding by considering international implications under Section 115. In a statement presented by Bruce Terris at the Hearing on June 19, Ontario's position was restated in that when the time comes for EPA to consider the remedies for transboundary pollution, it is essential that interstate pollution in the northeastern United States and international pollution in Canada be considered together. Ontario's views on EPA's obligation under Section 115 are set forth in a written request of May 28, 1981 to expand the scope of the Hearing.

Mr. Terris' statement of June 19 also addressed the status of the Hearings under Section 126. Mr. Terris drew the conclusion on the basis of arguments set forth in his statement that if EPA tentatively decides to grant the petitions, it must then publish a notice of proposed

rulemaking. After that notice is published, and after EPA has satisfied the requirements of producing information, the Agency is then required to give interested persons another opportunity to submit comments, orally and in writing. Ontario will take the opportunity at that time to file updated comprehensive material in relation to any proposed rulemaking. This stage of the proceedings therefore requires determination of the threshold question whether the evidence submitted by the petitioning states and others calls for an affirmative finding under Section 126. The second stage centres on EPA's proposed determination and the evidence as produced and placed on the rulemaking record.

The second point addressed by Mr. Terris was EPA's basic responsibility in these proceedings. On June 19, 1981 he stated:

"Congress has plainly told EPA in 1970 and, more emphatically, in 1977, that interstate pollution problems are to be resolved and that Section 126 is to be a mechanism to resolve them. Thus, EPA does not have the choice to allege lack of scientific certainty, to note the procedural or remedial difficulties or to raise other problems as reasons to throw up its hands. Instead, Congress imposed on EPA the duty, we submit, the nondiscretionary duty, to construe Section 126 so that it will work."

The third point addressed in Mr. Terris' statement is the placing of the burden in this proceeding. Clearly the petitioning state agencies have the initial responsibility to trigger Section 126. Nevertheless, EPA bears the responsibility to gather information relevant to these petitions, not to sit as a passive judge deciding whether the petitioners have met their burden of proof. It is not an umpire calling balls and strikes. Legal authority is cited for the proposition that EPA has the overriding responsibility to carry out the Act, including the prevention of interstate pollution. Whether the interstate impacts are examined in the context of review of a SIP or of a SIP revision or in response to a petition under Section 126, EPA retains the ultimate responsibility to ensure that interstate impacts prohibited by the Act are not occurring.

Fourthly, Mr. Terris submitted that the evidence presented in this proceeding by the petitioners and by Ontario and others, demonstrates conclusively the serious transboundary pollution problem affecting the north-eastern United States, as well as Canada.

Fifthly, Mr. Terris' statement rejected the notion that lack of sufficient information requires that no action be taken until elaborate research programs are completed. Congress wanted EPA to act even where the scientific certainty could not be achieved. Legal

authority was cited for the proposition that since the statute is precautionary in nature, it is the duty of EPA to carry out the statute using the best information available.

Sixthly, Mr. Terris rejected the notion that Section 126 is violated only if the pollutants transported from out-of-state sources make it impossible for the receptor state to achieve attainment with the National Ambient Air Quality Standards. He submitted that the language and legislative history of Section 126 make clear that the Section applies if the source state significantly interferes with the attainment or maintenance of the national standards. We submit that this test is plainly satisfied when significant amounts of pollution are transported into the recipient state and, as a result, the recipient state is forced to impose significantly more stringent requirements on its pollution sources than the source state. In these circumstances, we submit that Section 126 has been violated even if there is no current violation of national standards.

The seventh point addressed by Mr. Terris was the question of considering the cumulative impacts of sources. It was pointed out that EPA had itself taken the position in legal proceedings that Section 126 will be an appropriate forum of evaluating claims regarding cumulative out-of-state sources if Section 126 is not to be left an empty shell.

The following material is submitted to further substantiate the scientific and legal arguments presented in Washington during the June 19, 1981 Hearing Process.

3. EMISSIONS

In both the March 27th and June 19th submissions, pollutant emissions were discussed with relation to their impact on New York, Pennsylvania and Ontario following transport to these regions. This topic has been thoroughly reviewed and reported upon in January, 1981, by the Work Group 3B¹ of the Memorandum of Intent and updated by Work Group 2² in July, 1981. Below is a summary of the available information on sulphur dioxide and nitrogen oxide emissions for the eastern North American Region.

3.1 Current Emissions of SO₂

The total SO₂ emissions for North America in 1980 are estimated to be about 33.6 million tonnes with the ratio of U.S. to Canadian emissions at 7. to 1. Thermal power plants (mainly coal-fired) are the primary source and contribute about 49% to the total U.S.-Canada SO₂ emissions. The primary contributor to present SO₂ emissions differs in the U.S. and Canada. In the United States, power plants are the main source (55%) whereas in Canada, it is the non-ferrous smelters (43%). In actual quantities, U.S. power plants emitted about 15.8 million tonnes in 1980 and the Canadian non-ferrous smelters about 2.0 million tonnes.

Current emissions of SO₂ for the contiguous U.S. are about 28.8 million tonnes with 71% of these emissions (20.4 million tonnes) arising from sources located in the eastern U.S., i.e., in states east of the Mississippi River. Thermal power plants, the primary source, contributed about 55% to the U.S. total. In 1980 the fifty largest utility point sources of SO₂ emissions in the U.S. emitted 7.5 million tonnes, about 26% of the U.S. total. As these 50 utility sources are located in the eastern U.S., they contribute about 37% of SO₂ emissions there.

For Canada, estimated SO₂ emissions in 1980 are 4.8 million tonnes with about 83% of these emissions (i.e., 4.0 million tonnes) arising from sources located east of the Manitoba-Saskatchewan border (i.e., eastern Canada). Non-ferrous smelters (mainly copper-nickel) are the primary source and contribute about 43% of the total. Other industrial sources contribute about 22% and utility combustion sources contribute about 14% of the Canadian total SO₂ emissions. In 1980, the ten major SO₂ point sources contributed 2.6 million tonnes, about 54% of the total emissions.

For eastern North America, the 1980 SO₂ emission estimate is 24.4 million tonnes and the ratio of U.S. to Canadian emissions is 6.1 to 1. Thermal power plants are

the primary source and contribute about 62% of the total emissions there. For the eastern U.S., approximately 71% of the SO₂ emissions come from utility combustion sources, the highest density of which occurs in the upper Ohio River Valley Region. Non-ferrous smelters contribute less than 1%. For eastern Canada, approximately 51% of the SO₂ emissions come from six copper-nickel smelters, two of which are located in each of the Provinces of Manitoba, Ontario and Quebec. Power plants contribute only 16% of the SO₂ emissions in eastern Canada, and are primarily sources located in southern Ontario. In 1980, the top 50 point sources of SO₂ emissions in eastern North America emitted 9.2 million tonnes of SO₂, about 38% of the regional total.

3.2 Current Emissions of NO_x

The total NO_x emissions for North America in 1980 are estimated to be about 22.1 million tonnes with the ratio of U.S. to Canadian emissions at 11 to 1, and about 41% of the emissions come from the transportation sector. The utility sector contributes about 27% of the total NO_x emissions. The primary NO_x emission source in both the U.S. and Canada is the transportation sector (40% in the U.S. and 50% in Canada). NO_x discharges from power generating stations contribute about 28% to the total NO_x emissions in the U.S. and about 14% to the Canadian total.

Current emissions of NO_x for the contiguous U.S. are about 20.2 million tonnes with about 85% of the emissions occurring in the eastern U.S. For Canada, estimated NO_x emissions in 1980 are 1.8 million tonnes, with about 65% of these emissions (i.e., 1.2 million tonnes) arising from sources in eastern Canada. For eastern North America, present NO_x emissions are about 19.0 million tonnes. The ratio of U.S. to Canadian emissions in the east is roughly 16 to 1.

3.3 Natural Emissions of Sulphur

The total natural emissions of sulphur into the atmosphere in Canada have recently been estimated to be 0.51 million tonnes of S. Of this total, biogenic emissions accounted for 0.32 million tonnes. For eastern Canada, natural emissions of sulphur are about 0.30 million tonnes (58% of the Canadian total) with biogenic emissions contributing 0.20 million tonnes. In contrast, preliminary biogenic sulphur emission estimates for the eastern U.S. (SURE region) are less than 0.10 million tonnes S with about 50% of the emissions occurring in the summer.

3.4 Primary Sulphate Emissions

The principal primary sulphate inventories for the eastern U.S. (SURE region) vary considerably in their estimates. Preliminary indications are that primary sulphate emissions for this area are less than 1.0 million tonnes/yr. This issue is currently being addressed by Work Groups 2 and 3B of the U.S./Canada Memorandum of Intent.

3.5 Seasonal Differences

Seasonal variations in the sulphur dioxide and nitrogen oxide emissions for the various EPA regions in eastern North America appear to be insignificant.

3.6 Emissions Summary

Therefore, the thermal power plants and the transportation sector in the eastern United States are primarily responsible for the sulphur dioxide and nitrogen oxide emissions respectively. The contributions of primary sulphates and natural sulphur compounds to the emissions total are insignificant. As well, seasonal variations in emissions are considered to be small when compared to the total outputs.

References - Chapter 3

1. United States-Canada. Memorandum of Intent on Transboundary Air Pollution. Work Group 3B.

Work Group 3B: Engineering, Costs and Emissions Interim Report. January 15, 1981. Submitted to the Coordination Committee in Fulfillment of the Requirements of the Memorandum of Intent. Signed by United States and Canada on August 5, 1980. Co-chairmen, Kurt W. Riegel, United States and M.E. Rivers, Canada.

2. United States-Canada. Memorandum of Intent on Transboundary Air Pollution. Work Group 2.

Phase II working report by Work Group 2, Atmospheric Sciences and Analysis. Report No. 2-15: July 10, 1981. Submitted to the Coordination Committee in Fulfillment of the Requirements of the Memorandum of Intent. Signed by United States and Canada on August 5, 1980. Co-chairmen H.L. Ferguson, Canada and L. Machta, United States.

4. METEOROLOGY, LONG RANGE TRANSPORT AND POLLUTION EPISODES

The regional transport of pollutants over hundreds or even thousands of kilometres before they are wet or dry-deposited to the earth's surface has been described by numerous authors.¹⁻¹³ Several of these studies are concerned with the long range transport of pollutants into Ontario from the highly industrialized regions of the United States, south of the Great Lakes. The meteorological conditions which prevail when these materials are transported into Ontario are associated with a high pressure system located over, or to the east ("back of the high") of, Southern Ontario. By contrast, lower pollutant concentrations are associated with days when a high pressure system is located to the west of the region ("front of the high"). The flow of air under the "back of the high" situations is from south of the Great Lakes, thus traversing a region of high emissions, while under "front of the high" situations, air flow is from north of the Great Lakes over a region of low emissions.

In this presentation we will show that transboundary transport of air pollutants is occurring and that these air pollutants are causing environmental problems for this Province. The case histories presented for Ontario are indicative of typical long range transport incidents

which would also affect such states as New York and Pennsylvania.

This Section 126 Hearing was designated to examine effects of emissions on National Ambient Air Quality Standards. In this section Ontario wishes to discuss the long range transport of such pollutants as SO₂, ozone and particulate matter. Since we are dealing with long range transport, time is available for atmospheric chemistry to alter these pollutants to form other secondary constituents such as sulphates and nitrates. It is our contention that when dealing with particulate matter, sulphates and nitrates must be considered as part of the entire picture.

It should also be pointed out that Ontario air standards and/or ambient air quality criteria are different from those in the United States. In some cases therefore, standards or criteria are exceeded in Ontario, while the pollutant levels would have been in compliance in the United States. Therefore as a result of emissions in areas remote from Ontario, and the subsequent long range transport and transformation of these materials, this Province is, as is pointed out in the following case histories, prevented from attaining and maintaining its objectives for ambient air quality.

4.1 Sulphur Dioxide

Traditionally transboundary air pollutant movement studies have involved ozone and fine particulate matter. However, Ontario has also documented the movement of gaseous sulphur dioxide into its airspace. One such major event occurred in February, 1979 when the concentrations of SO₂ and particulate matter were elevated and these concentrations led to the requirement of a reduction in emissions by industries in three Ontario cities.

On February 19 and 20th, 1979, a large high pressure area moved eastward from south of the Great Lakes to the Atlantic coast. Prior to the 19th, Southern Ontario and the Great Lakes States were under the grip of a prolonged cold, dry spell with temperatures averaging about -15°C, the cold weather causing a higher energy demand for heating which resulted in more emissions of SO₂ and particulate matter than normal.

As winds shifted in Southern Ontario on the 19th to the south and southwest behind the high pressure area, SO₂ concentrations began to increase across the entire Ontario monitoring network. The air mass was very stable with an intense nocturnal ground-based inversion and overrunning warmer air aloft. This warmer air formed a

strong lid limiting the vertical mixing and providing the conditions for the extended transport of pollutants in higher concentrations into and across Southern Ontario during the 19th and 20th.

With the establishment of southerly winds in Southern Ontario, SO_2 concentrations began to increase at all stations in the monitoring network. The increase began in the southwest late on the 19th and in the eastern portion of the Province by mid-day on the 20th. Twenty-four hour average concentrations on the 19th ranged from non-detectable levels to a maximum of 0.04 ppm while on the 20th the average levels were as high as 0.10 ppm with peak hourly average concentrations up to 0.22 ppm.

The evidence of the distant transport of SO_2 is clearly indicated by the measurement at rural stations. Inverhuron on the shore of Lake Huron which rarely records hourly levels above 0.02 ppm recorded a 24-hr. average 0.04 ppm on the 20th. The rural Simcoe station located north of Lake Erie recorded a 24-hr. average of 0.07 ppm. There are no significant local sources of SO_2 downwind of these stations in the southwest or south directions. Based on the concentrations at these rural monitors, it has been estimated that about 50% of the sulphur dioxide measured in Ontario originated in the United States.

Total suspended particulate matter (TSP) measured by high volume samplers on the 20th was well above normal for a mid-winter day averaging 90 ug/m^3 for both urban and rural locations. Over one-third of the monitoring stations exceeded the Ontario desirable criterion for particulate matter of 120 ug/m^3 . Several other stations were within 10% of exceeding that figure.

The sulphate component of the TSP was also much higher than normal during winter providing further evidence of long range transport. The sulphate component averaged almost 30% of the TSP measured. The maximum sulphate concentration measured on the 20th was 67.5 ug/m^3 .

Reduced visibilities have been related to high sulphate concentrations.¹⁴ Visibilities at Ontario airports were at 20 km on the afternoon of the 19th prior to the incident. On the afternoon of the 20th the visibilities were reduced to the range of 5 to 10 km.

Nitrate concentrations in particulate matter were also high, accounting for from 4-14% of the particulate concentration. The combination of sulphate and nitrate in the measured particulate matter, therefore comprised between 20 and 47%.

During the incident of February 19-21, the Ontario Air Pollution Index (API) Alert System, designed to protect public health, reached the Advisory Level of 32 in three Ontario cities where significant sources were requested to curtail operations. Sarnia in the southwest was the first to reach 32 at 1000 LST (Local Standard Time) of the 20th. The API peaked at 43 at 1500 LST and remained at that level for six hours. Hamilton reached 32 at 0400 LST and Toronto at 0600 LST of the 21st. The maximum API at Hamilton and Toronto were 34 and 33 respectively. Although the API was high in the other Ontario cities, the Advisory Level was not exceeded.

The air entering Ontario on the 20th and 21st has been traced by back-trajectory analysis to the area south of the Great Lakes, a region of high SO₂ emissions. When the winds shifted to the west and northwest on the 22nd, concentrations of sulphur dioxide fell to near zero at rural monitoring sites.

Although the incident described above reached major proportions with regard to the degree and extent of elevated SO₂ concentrations and the consequences thereof, Ministry monitoring programs have recorded a few moderate events each year and numerous minor intrusions of SO₂ into the Province as a result of long range transport from the area to the south of the Great Lakes.

4.2 Particulate Matter

The Ministry of the Environment monitors total suspended particulate matter using glass fibre filters in a high volume sampling network across the Province. Regional episodes of elevated total suspended particulate often have associated with them higher levels of sulphates and nitrates than are normally monitored. Although it is now generally accepted that errors can occur when sampling sulphates and nitrates on glass fibre filters, the concentrations presented are relative in nature and the elevated levels are indicative of episodes of long range transport of these secondary pollutants. Artifact sulphate is formed from absorption and conversion of sulphur dioxide, contributing possibly up to 5 ug of sulphate per cubic meter of air sampled. The magnitude of errors associated with particulate nitrate sampling is more difficult to assess, since both positive and negative interferences are possible and to date have not been reliably estimated.

4.2.1 Sulphates in Particulate Matter

Studies of sulphates in particulate matter in Ontario, eastern Canada, and the northeastern United States¹⁻⁹ have shown that high sulphate concentrations are generally associated with air flows from the region

south of the Great Lakes. As with other pollutants involved in long range transport,^{5,11} lower sulphate concentrations were measured on days with northerly air flows. At Simcoe, a rural monitoring site located near the northern shore of Lake Erie, the average sulphate concentration during the 1976-80 period was 6.3 ug/m^3 when the prevailing weather pattern had a high pressure centre to the west of Southern Ontario ("front of the high", northerly winds) and 12.3 ug/m^3 when a high pressure centre lay to the east ("back of the high," southerly winds). In Toronto, an urban monitoring site, located near the north shore of Lake Ontario, the 1976-79 average concentration of sulphate was 7.2 ug/m^3 for "front of the high" situations and 14.6 ug/m^3 for the "back of the high" conditions.

Since the centres of high pressure are generally stable parcels of air, sulphates and their precursor, sulphur dioxide injected into the air mass, may be transported over long distances before being removed. These centres, therefore, may be used as tracers of sulphate sources. Since the area to the south of the Great Lakes is a region of high sulphur dioxide emissions and the area north of the Great Lakes is low in sulphur dioxide emissions, a high pressure centre moving over, either north or south of the Great Lakes, should have sulphate concentrations indicative of the quantity of emissions

within the area. The average concentration of sulphates at Toronto was 10.6 ug/m^3 for high pressure centres coming from the south, and 8.8 ug/m^3 for those coming from the north.

Periods with high sulphate concentrations across the Southern Ontario monitoring network are mainly a warm season phenomenon. Warm season high sulphate incidents are accompanied by high ozone concentrations and reduced visibility. Cold season high sulphate incidents are less frequent and may be accompanied by high sulphur dioxide and nitrate concentrations. Fifteen major incidents in the 1976-80 period occurred across the Southern Ontario monitoring network. Seven of the fifteen incident days had southerly flows and "back of the high" weather conditions, none occurred with "front of the high" weather regimes.

One previously described cold season incident, February 20, 1979, resulted in 84% of the Ontario monitoring network of 34 stations exceeding 20 ug/m^3 of sulphate.⁹ The prevailing weather on the 20th was in the "back of the high" category. Back-trajectory analysis indicated that the air flow during the measurement period was from south of the Great Lakes.

High sulphate concentration incidents occurring on sunny summer days are characterized by a haze in the lowest thousand meters of the atmosphere extending for hundreds or thousands of kilometres covering both urban and rural areas. Satellite photographs of eastern North America have shown large hazy air masses present in cloud-free regions.⁸ Further investigations have revealed that this air is characterized near the surface by low visibility and high concentrations of sulphate particles and ozone. By analyzing a series of these photographs, the path history of the "smog area" can be reconstructed.

The history of one such event (August 16-28, 1976) showed the "smog area" south of the Lower Great Lakes and spreading over the entire Lower Great Lakes region by August 22nd. A weak cold front pushed the "smog area" southward on the 23rd, but it again moved northward across Southern Ontario on the 26th. Particulate sulphate concentrations exceeded 40 micrograms per cubic metre ($\mu\text{g}/\text{m}^3$) at several Ontario sites during this period. In addition, the origin of the sulphate-laden air, reported in an area extending from Windsor to Quebec city, was demonstrated to be the Ohio, Pennsylvania, and West Virginia regions.⁵ The concentrations of sulphates reported at ground level over Ontario, Quebec and the northeastern United States on August 16, 22 and 28

indicate that the measured levels of sulphates contributed to the reduction in visibility that was evident in satellite photographs.⁸

4.2.2 Nitrates in Particulate Matter:

Studies of nitrates in particulate matter measured across Southern Ontario¹¹⁻¹³ have also indicated that higher nitrate concentrations occurred when air flowed from the region south of the Great Lakes than when the air came from north of the Lakes. In general, average nitrate concentrations for all weather conditions are higher in the extreme southwestern part of the region and around the western Lake Ontario shoreline.

When nitrate concentrations were correlated with the type of weather prevailing on the day of measurement¹¹, it was found that the highest average concentrations occurred when a high pressure system was located over or to the east ("back-of-the-high") of Southern Ontario. The lowest concentrations were found on days when a high pressure system was to the west of the region ("front-of-the-high"). For the 17 station network in Southern Ontario, the ratio between the back and front of the high situations was nearly a factor of two. The five-year nitrate average concentration for a rural station at Simcoe, located on the north shore of Lake Erie was 4.0

ug/m³ under "back of the high" situations and 2.3 ug/m³ for the "front of the high" cases. The flow of air under the "back of the high" situation is from south of the Great Lakes thus traversing regions of high nitrogen oxide emissions. Under "front of the high" situations, air flow is from north of the Great Lakes over regions of low nitrogen oxide emissions.

Since there is a large difference in the amount of nitrogen oxide gases emitted in the area north and south of the Great Lakes, tracing the direction of movement of a high pressure centre should give an indication of the source contributions of the two areas.

Since the centre of high pressure is generally a stable parcel of air, nitrogen oxides injected into the air mass as it passes over the source region will likely remain aloft and be converted to nitrates within the air mass. In this manner, nitrates will accumulate and be transported over long distances until removed by dry or wet deposition or chemical transformation.

High pressure centres were partitioned according to the direction from which they approached Southern Ontario (north, south, or west) during the 1976-1978 period. Two locations were chosen for this study: the downtown Toronto and the rural Pickering monitoring stations -

both daily monitors.¹³ The average nitrate concentration on days when the centre arrived from the north or northwest was 3.12 ug/m^3 for 58 occasions in Toronto and 2.42 ug/m^3 for 50 cases in Pickering. When the centres came from the south or southwest, concentrations rose to 5.92 ug/m^3 (for 48 days) in Toronto and 5.17 ug/m^3 (for 46 days) in Pickering. The difference of about 2.8 ug/m^3 at both sites was statistically significant. Centres originating in the west (i.e., those which had no definite movement from a south or north direction) had concentrations of 3.74 ug/m^3 for 36 cases and 3.73 ug/m^3 for 31 cases for Toronto and Pickering respectively.

Detailed studies of periods when nitrate concentrations were high (in excess of 10 ug/m^3) over southern Ontario have shown that nine of the eleven high nitrate episodes (days with nine or more cities measuring nitrate concentrations in excess of 10 ug/m^3) occurred when the high pressure system was either over or to the east of the area.¹³ Five of the days were "back of the high" type. Of the four periods when the high was over the region, two moved in from the south and two from the west, both over regions of high emissions.

To illustrate the weather situation in relation to high nitrate concentrations, we will look closely at the period 5th-20th of February, 1977.^{12,13}

During this period nitrates were measured in excess of 9.9 ug/m^3 at 68 stations. Most of these occurred on two of the three regular nitrate sampling days (6-day, high-volume sampling schedule). On the 12th of February, 33 stations exceeded the 9.9 ug/m^3 level, and on the 18th of February, 21 stations were in excess. The daily monitoring network at three sites (Hamilton, Toronto and Pickering) shows that elevated levels lasted for several days with fairly good correlation among the three sites.

On the 5th of February, a large cold air mass in northern Manitoba began pushing southward into the northern Mississippi Valley. During the three day period, 5th to 7th of February, strong winds from the northwest and cold temperatures dominated southern Ontario. The mean temperature measured during the period at Toronto International Airport was -14.6°C . Prevailing winds were from the northwest at 20.5 km/hr . Nitrate concentrations were quite low. The nitrate network of 30 reporting stations averaged 1.7 ug/m^3 on February 6th. Back-trajectory analysis indicates that the flow was over low nitrogen oxide emission areas to the north.

During this time period, the high pressure centre from Iowa moved eastward across Illinois, Ohio, and Pennsylvania before turning south on February 9th. As the system moved to the east, the nitrate levels rose at

the daily monitoring sites, exceeding 15 ug/m^3 at Hamilton and Toronto on the 10th. A low pressure cell crossed the region on the 11th leaving a stationary front across Northern Ontario on the 12th. An intensifying storm system lay to the west of Lake Superior on the morning of the 12th and the cold high had settled off the Carolina coast. Temperatures in southern Ontario rose above the freezing mark with moderate WSW winds.

Across the network, nitrate levels were reported on the 12th in excess of 9.9 ug/m^3 at 33 sites. The average for the 35 sites reporting was 17.4 ug/m^3 .

The 24 hour back-trajectories show that the air entering southern Ontario had passed over northwestern Ohio. The trajectory to London, Ontario where the nitrate concentration was 21.0 ug/m^3 shows that the air had passed over Lake Erie and rural Ontario after crossing Ohio. Since nitrate inputs over the lake and a rural area in winter are unlikely to be of consequence, the source for high nitrate levels originated in the air mass south of the lake. Nitrate levels were of similar concentration in Windsor (in excess of 20 ug/m^3) and the trajectory shows air originating in nearly the same location.

As the storm system moved across the region, nitrate levels fell at the daily monitors. With the establishment of a northerly flow pattern in the wake of the storm and ahead of another cold air mass in northern Manitoba, nitrate levels fell to values similar to the 5th to 7th of February period. This high pressure system moved along the same general path as the previous one. By the 18th, the region was again in the return circulation of the high with a low pressure system approaching from the north of Lake Superior. Nitrate levels again rose averaging 12.5 ug/m^3 with 21 of 32 reporting stations in excess of 9.9 ug/m^3 .

Trajectories to three sites (London, Windsor, Toronto) show flow again across northwestern Ohio. With the passage of the cold front and return to northerly winds on the 19th, nitrate concentrations dropped to less than 5 ug/m^3 .

The trajectory analyses above and the results of previous studies^{11,13} which showed that nitrate concentrations increased when southerly flow was initiated as a high pressure system moved to the east of Ontario, when coupled with the low concentrations found when the air originated to the north of the Great Lakes, strongly indicate a source region for nitrates south of the Great Lakes. Source inventories for eastern North America show

that the largest emitting areas of nitrogen oxide gases are located to the southwest of southern Ontario.

4.3 Ozone

In recent years, the generation, build-up and dissipation of ozone concentrations in the atmosphere over Southern Ontario have been studied by numerous researchers.^{3,15-18} These studies indicated that the summer ozone life-cycle is strongly influenced by synoptic motion systems. As with sulphates and nitrates, widespread elevated ozone levels are found typically on the rear sides of anti-cyclones or in the warm sectors of cyclones, and are associated with very warm, moist air moving into Ontario from the south to southwest directions (Figure 4.1). The transport mechanism for elevated ozone levels has been identified with synoptic-scale motion systems which advect ozone and its precursors, nitrogen oxides and hydrocarbons which are emitted in power plant and urban plumes, over distances of several hundred kilometres. On the regional or local scale, ozone levels in Ontario are enhanced downwind of urban areas, and during lake-breezes and onshore-flow fumigations.

Since 1975, ozone has been monitored continuously by chemiluminescent instruments at over 20 urban and rural locations in Southern Ontario (Figure 4.2). For the years 1976-1980 inclusive, each of the monitored locations in the network recorded ozone levels in excess of Ontario's ambient air quality criterion of 80 ppb (hourly average). The maximum hourly average ozone concentrations for the 20 stations for the 5 year period varied from 83 ppb at Ottawa in 1980, to a high of 218 ppb in 1976 at the Holland Marsh station, 50 km north of Toronto (Table 4.1).

Elevated ozone levels over 80 ppb most commonly occur over widespread areas (more than 8 monitoring sites) during the spring and summer. The number of such days ("episode days") varies considerably from year to year due to fluctuations in the meteorological conditions, but the frequency is significant. For example, in 1978 there were 43 days of elevated levels, while in 1979 and 1980 there were 14 such events.

Figures 4.3, 4.4, 4.5 and 4.6 show the distribution of average afternoon ozone maxima for the "episode" days during 1976, 1977, 1978 and 1979. In Ontario the elevated levels of ozone are typically recorded over an area 700 km in length (Windsor to Kingston) and within 100 km of the north shoreline of the lower Great Lakes.

Concentrations are generally highest near Lake Erie and Lake Ontario, and decrease with distance inland.

Other investigations¹⁹⁻²¹ suggest that this area of Southern Ontario is in the northern extension of ozone-laden air centered over the northeastern United States. High levels of ozone just north of Lake Erie are likely due to long range transport as there are no major sources of the precursors in this area of Ontario.

Ozone episodes are associated with specific meteorological conditions. During such episodes, maximum temperatures average about 28°C, afternoon dew points average about 20°C, and the visibility is limited to about 8 km. The winds are generally from the south to southwest direction. Such conditions may persist for a few days in Ontario when there is a broad area of high pressure lying quasi-stationary over the southeastern United States. The synoptic conditions have been described in detail by Vukovich et al.²²

Wolff and Lioy²¹ studied the prolonged ozone episode that occurred during the heat-wave period of July 12-21, 1977, when a broad area of high pressure remained quasi-stationary over the eastern United States. Figure 4.4(a) shows the ozone pattern for July 15 for southern Ontario and the eastern United States. It may be seen that

Southern Ontario is on the edge of a very large area of high ozone concentrations associated with the return flow around the high pressure system. A mixed layer air parcel trajectory of the air entering Southern Ontario is also shown in Figure 4.4(b). This trajectory indicates a path that passed through regions of the United States that have both high hydrocarbon and NO_x emissions. Both the precursor pollutants and their photochemical reaction products are apparently advected in the air mass over large distances. During an episode, the ozone levels peak during the daytime with mixing through the boundary layer, and are significantly reduced at night due to the trapping of pollutants above the surface-based nocturnal inversion.

4.4 Acid Deposition

In general, back-trajectories of the air parcels show that air arriving in Southern Ontario with high ozone and sulphate concentrations originated south of the Great Lakes. In contrast, air of northerly origin has been demonstrated to have much lower pollutant concentrations. U.S. studies have shown that high pollutant levels in the northeastern United States were associated with air flows from the Ohio Valley and comparably clean air was associated with a northerly circulation from Canada.^{8,19,22-24}

The association of much of Ontario's primary and secondary air pollution with U.S. source regions has been accomplished by means of trajectory analysis whereby weather records are used to track the winds backward in time to determine the geographical areas responsible for the air quality characteristics of a given air mass.

Kurtz and Scheider carried out a back-trajectory study (See Appendix 4) in which weather maps were analyzed along with precipitation samples taken over a three-year period in the Muskoka-Haliburton region, an environmentally sensitive area of south-central Ontario about 200 km north of Toronto.

Back-trajectory analysis indicated that 80% of the acid which was wet-deposited came with air masses from the south and southwest. While Ontario sources to the south also contribute to this percentage, the relative magnitude of these is small compared to U.S. emissions south of the study area. It is therefore reasonable to assign most of the 80% figure to the U.S. sources.

The finding that high acidity in Ontario's precipitation is associated with air masses originating in the U.S. is supported by Whelpdale in an article which appeared in *Atmospheric Environment*.²

In a 1980 M.O.E. Report on Precipitation Quality in the Sudbury area, (See Appendix 3), the mean level of acidity in precipitation was determined for northerly and southerly air flows. Precipitation related to southerly air masses had, on average, over twice the acid content of precipitation from the north.

4.5 Satellite Air Mass Tracking

Many case studies of long range transport into southern Ontario have been documented by various researchers. These cases are characterized by hazy air masses in the Ohio Valley region which are transported across the border into Ontario. These hazy air masses, rich in photo-chemical oxidants and sulphate aerosols, are usually formed on the west side of a slow moving high pressure system. Lyons refers to these Persistent Elevated Pollution Episodes by the acronym PEPE. Although the "classic" PEPE is associated with summertime conditions, transboundary episodes have been documented throughout the year.

Apart from trajectory analysis for the determination of polluted air mass movements, satellite imagery and regional modelling have been used and are written up extensively in the literature. Both techniques produce results which reinforce the trajectory analysis findings.

Dr. Walter Lyons of MESOMET INC. has done extensive research into the use of satellite imagery for tracking polluted air masses. On behalf of the Ministry of the Environment, Dr. Lyons presented a video-demonstration of this powerful tool at the Section 126 hearings and a copy of his presentation was placed in the record. A copy of Dr. Lyons text is appended to this report, (See Appendix 5). In this work conventional meteorological satellite images are used to detect the formation and the spread of large scale pollution episodes.

The satellite is able to detect large clouds of aerosols in the lower several thousand feet of the atmosphere. Study of these images over time indicates

that these aerosols do not originate from local sources, but are the result of gases emitted several days upstream which underwent photochemical transformation into aerosols. These regional scale episodes can cover many States and extend far out into the Atlantic. Usually such episodes will persist for several days, and in some cases weeks, until a cold front sweeps clean unpolluted air into the region.

Lyons states that the primary source of precursors for these visibility-reducing aerosols is apparently SO₂ emanating largely from coal burning, tall stack power plants. He continues, that the concentration of major power plants and numerous minor sources in the eastern U.S. is high and thus, we would expect to find the maximum sulphate aerosol concentrations and other associated pollutants in this general region.

MESOMET have documented several pollution episodes, tracking them over extensive areas of the eastern U.S. and sometimes into Canada. This type of information reinforces other scientific data as to the origin, occurrence and ultimate destination of air pollutant related problems.

Having reviewed the above information, all of this scientific and monitoring data related to trajectory analysis, meteorological conditions, episode monitoring and satellite tracking of aerosols confirms that many of Ontario's difficulties in meeting its ambient air quality standards and criteria are related to the long range transport and transboundary movement of pollutants from the high emission areas of the eastern United States into Ontario.

	1976	1977	1978	1979	1980
HURON PARK	--*	137	134	123	120
WINDSOR	173	144	211	120	131
MERLIN	--	167	137	158	137
SARNIA	137	168	144	159	155
PETROLIA	--	146	148	148	125
LONDON	112	120	111	101	111
SIMCOE	139	133	171	148	99
KITCHENER	117	111	137	115	98
ST. CATHARINES	131	127	148	124	138
HAMILTON	128	93	119	112	107
TORONTO 1	138	110	135	155	121
TORONTO 2	--	--	102	106	77
SCARBOROUGH	142	107	128	165	108
NORTH YORK	139	--	140	99	125
ETOBICOKE 1	124	126	135	92	129
ETOBICOKE 2	106	111	116	126	107
MISSISSAUGA	--	--	129	134	120
OAKVILLE	124	122	142	129	109
HOLLAND MARSH	218	129	124	-	-
STOUFFVILLE	163	152	142	172	137
OTTAWA	96	91	133	96	83
CORNWALL	119	89	116	114	100
WESLEYVILLE	178	--	171	-	-
ORONO	162	176	181	149	-
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ONTARIO	218	176	211	172	155

* - no data available.

TABLE 4.1: MAXIMUM ONE HOUR OZONE CONCENTRATIONS (PPB).

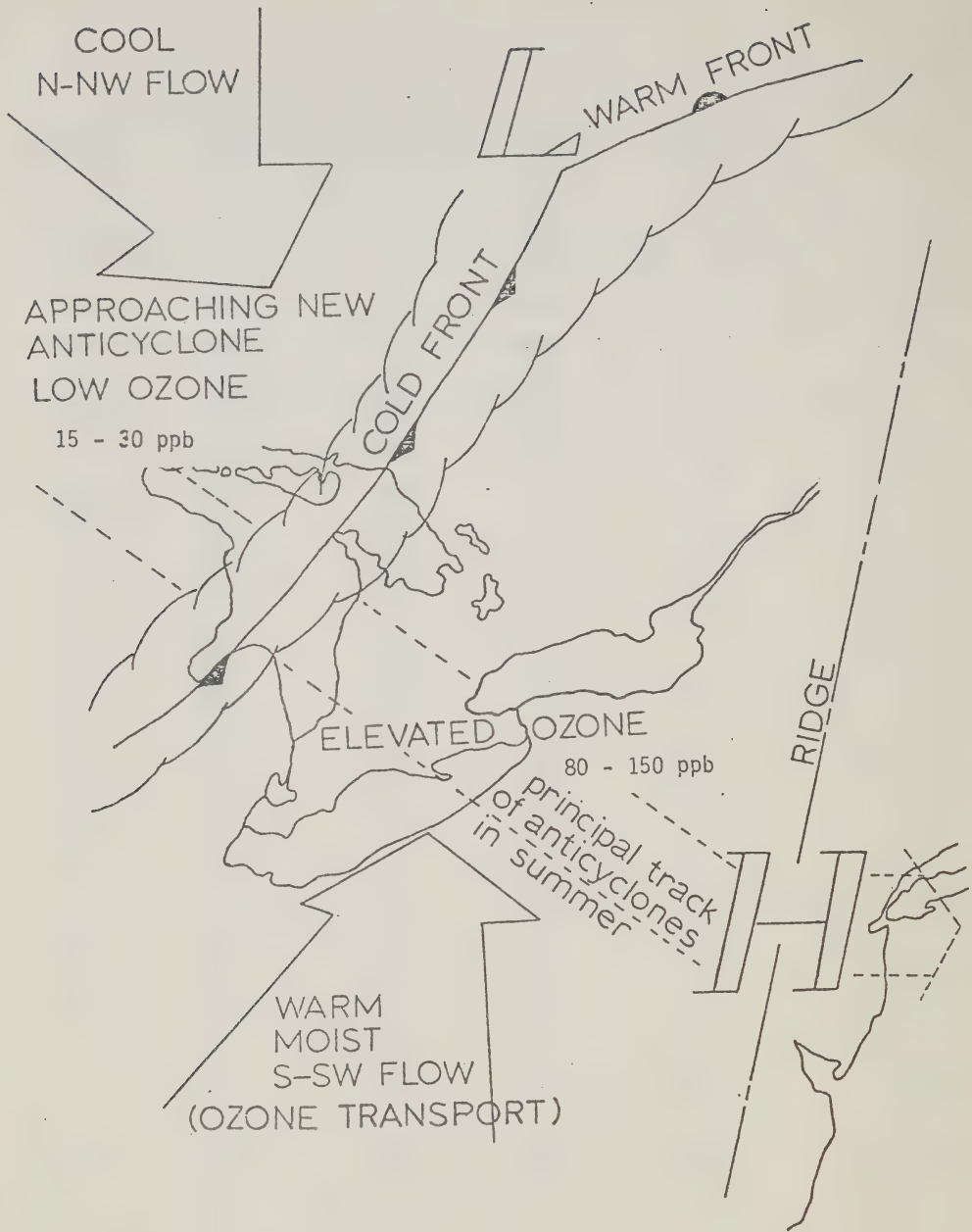


FIGURE 4.1: SYNOPTIC METEOROLOGY RELATED TO OZONE EPISODES.

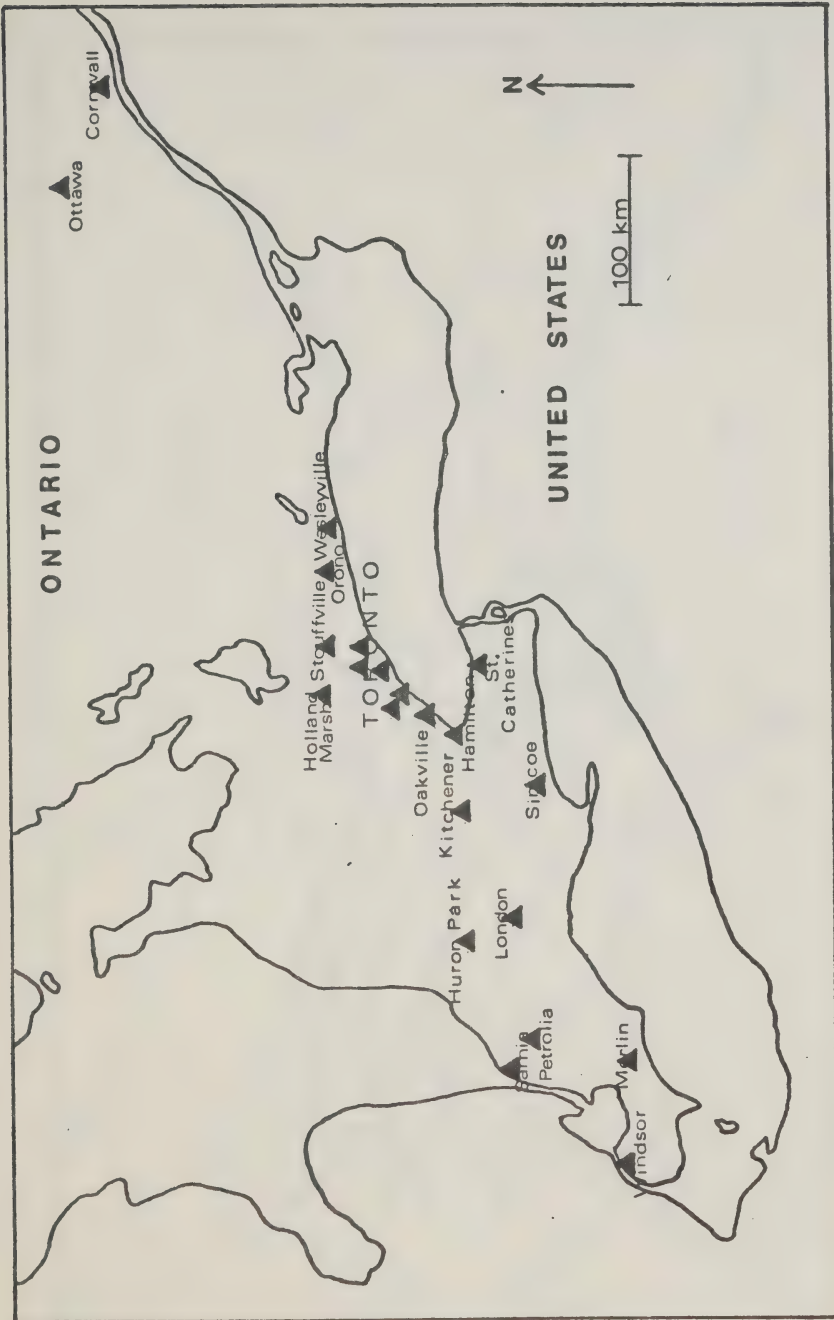


FIGURE 4.2: ONTARIO'S OZONE MONITORING NETWORK.

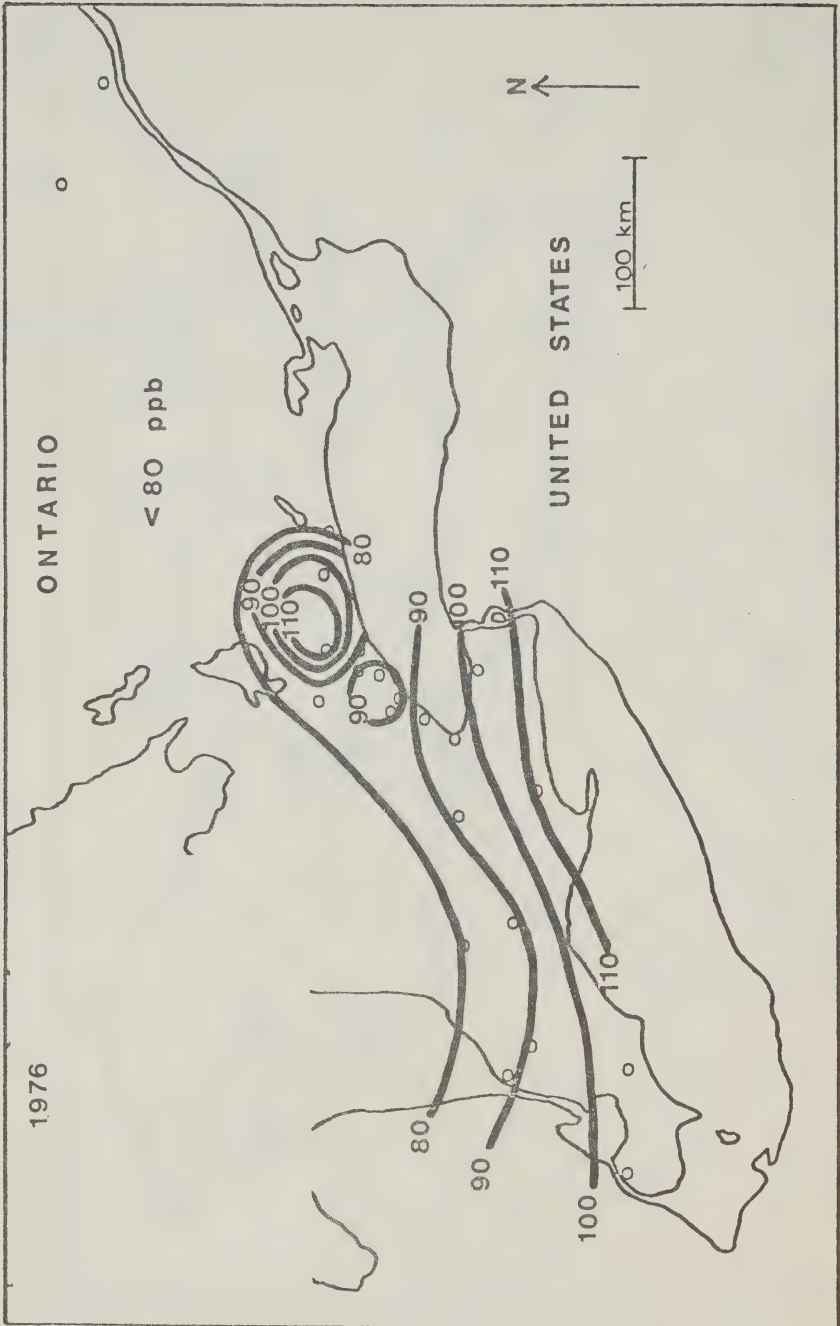


FIGURE 4.3: AVERAGE OZONE MAXIMA FOR 18 EPISODES.

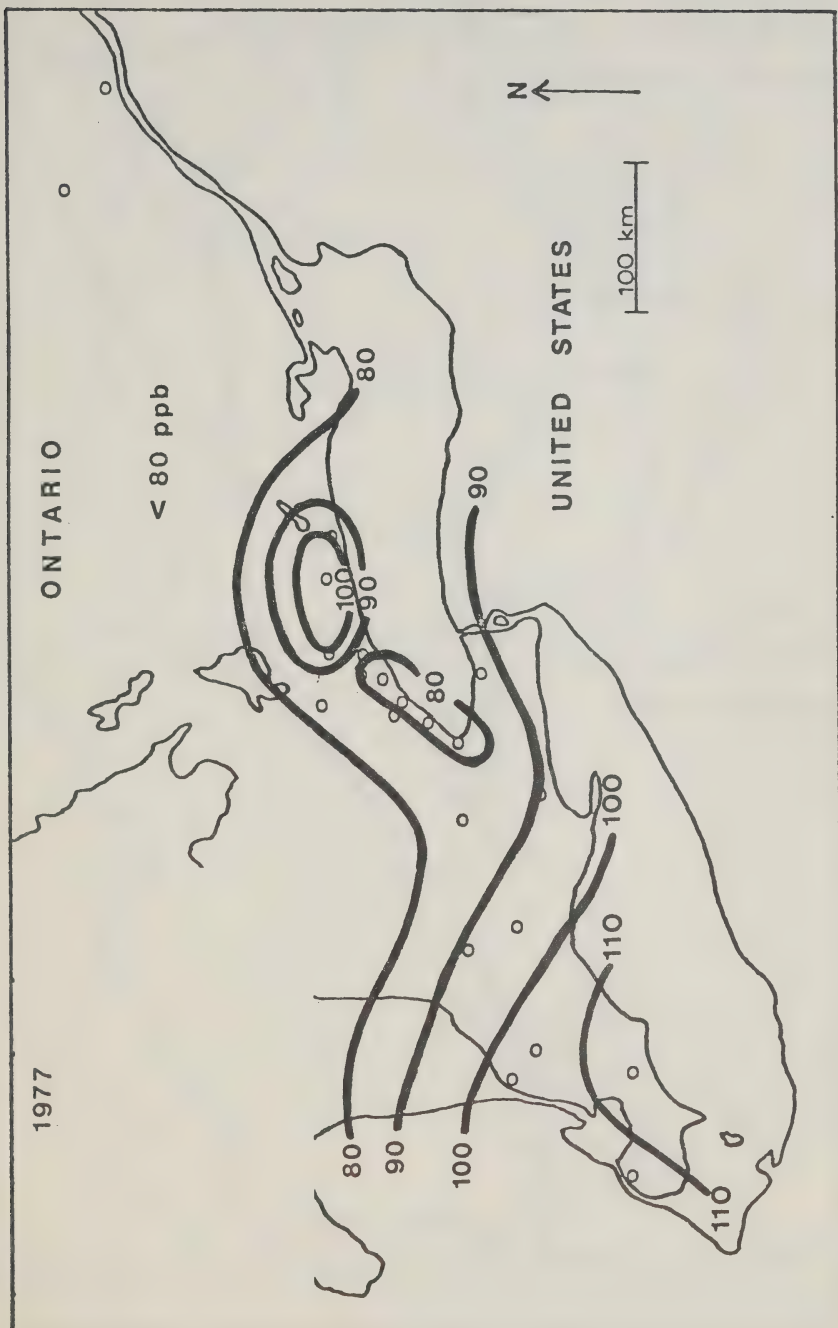
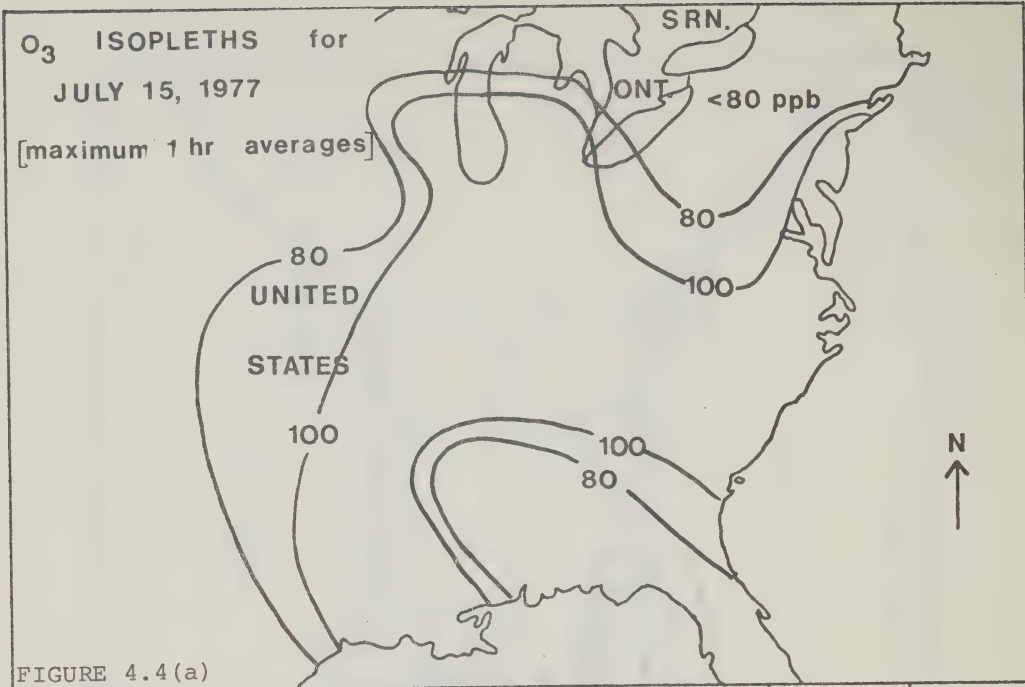
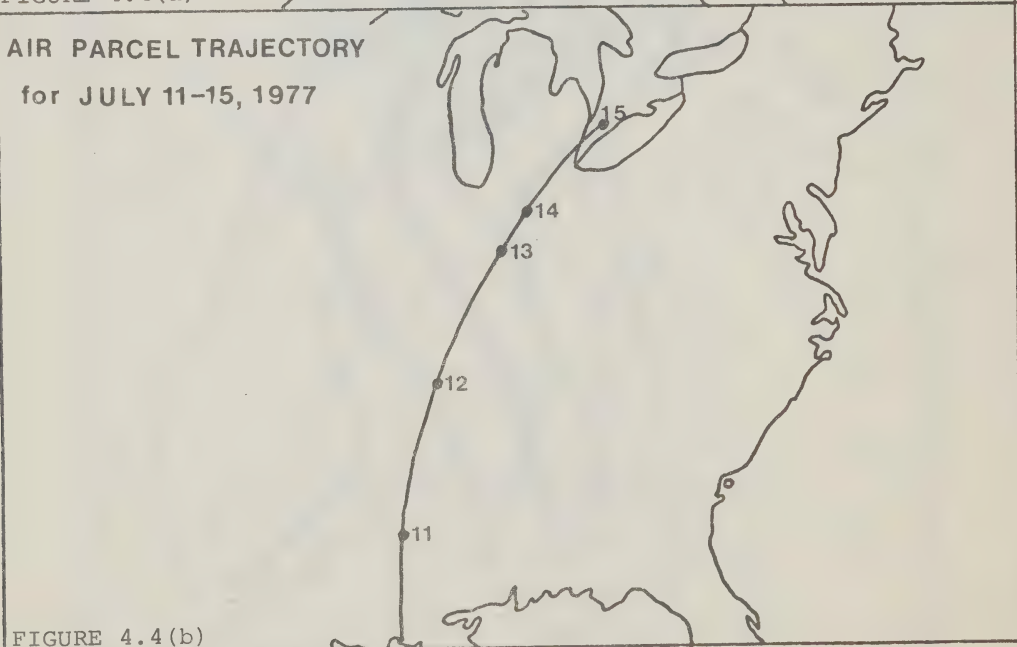


FIGURE 4.4: AVERAGE OZONE MAXIMA FOR 21 EPISODES.



AIR PARCEL TRAJECTORY
for JULY 11-15, 1977



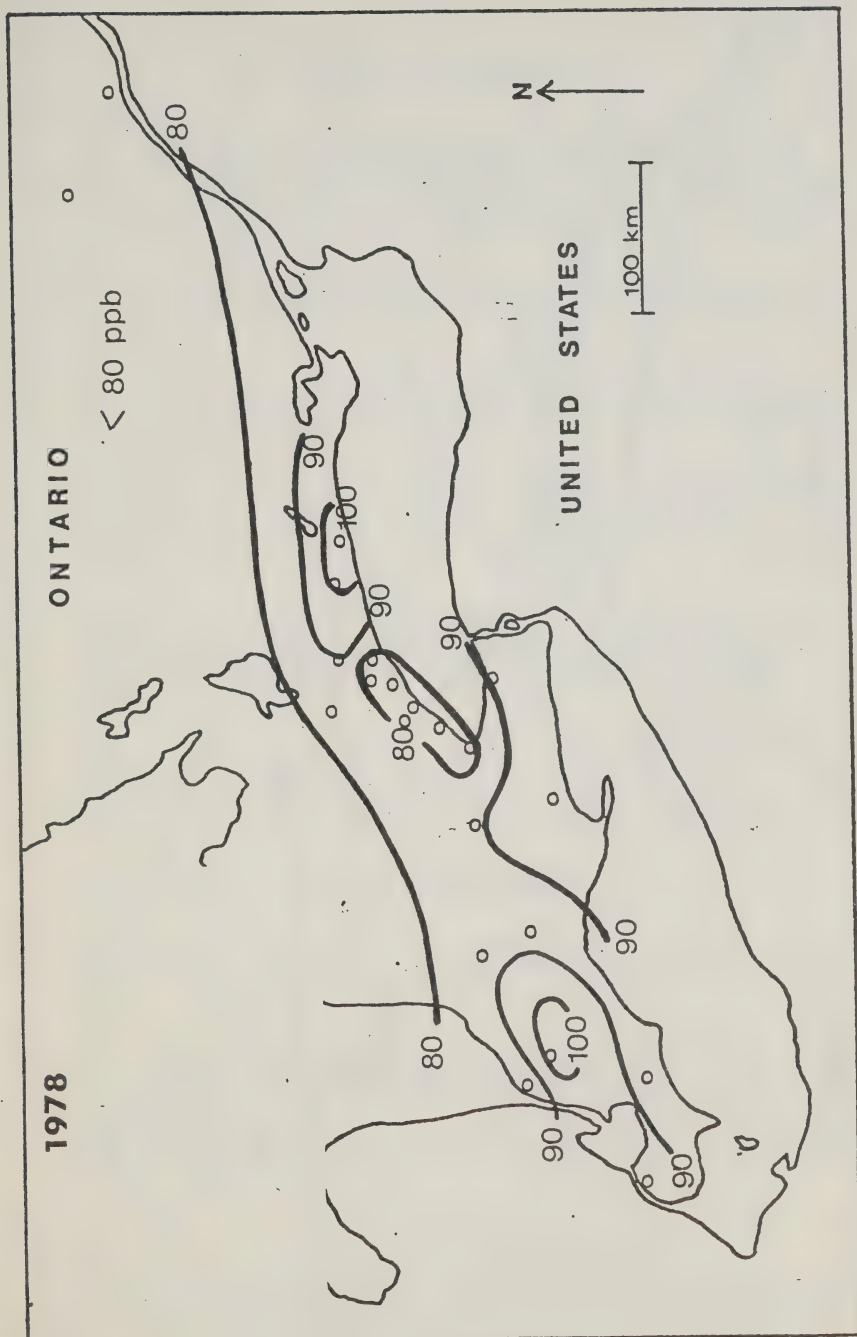


FIGURE 4.5: AVERAGE OZONE MAXIMA FOR 43 EPISODES.

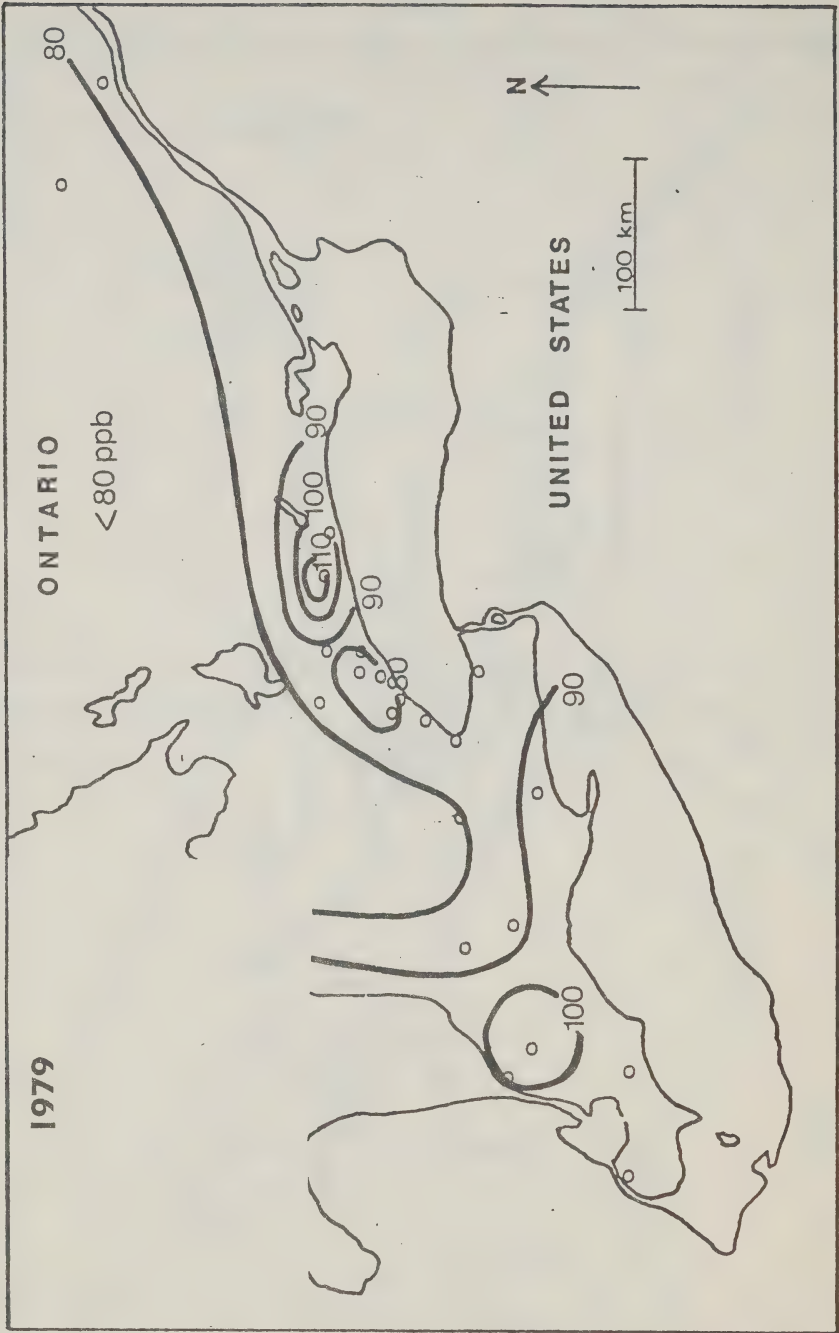


FIGURE 4.6: AVERAGE OZONE MAXIMA FOR 14 EPSIODES.

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5. ATMOSPHERIC CHEMISTRY

5.1 Introduction

As can be seen from the previous Section, atmospheric chemical transformations play a large role in the formation of aerosols characteristic of pollution episodes. Knowledge of the ultimate chemical species is important for deposition studies related to these problems. A thorough understanding of these atmospheric processes is also required for the parameterization of models subsequently used to predict source-receptor relationships. This latter topic will be dealt with in the Chapter on modelling.

At the Hearings in Washington, the Ontario delegation was given the impression that the evidence presented by this Province and by other jurisdictions and interested parties left the Hearing Panel feeling that there was an extreme paucity of data available on atmospheric chemistry and deposition. Therefore Chapters five and six comprise a short overview of what is actually known about these two important areas. As stated previously in this document, it is important to relate emitted materials to deposited products. Therefore, we need to know and understand what changes SO_2 and NO_x undergo while being transported over long distances. As a consequence, SO_2 and NO_x cannot be

considered in isolation, but must be reviewed in the total emission-to-deposition context. It is felt that although our knowledge is incomplete, a considerable body of scientific evidence is available for our use, especially in the modelling efforts.

Since our present knowledge of all the phenomena of atmospheric chemistry is not complete, it is comparatively easy to argue any particular viewpoint by selecting from the available evidence, and it is also easy to pick holes in isolated arguments. Only by considering carefully everything that has been reported can one obtain the full picture.

What is definitely known is that large stationary combustion sources, power plants in particular, emit several pollutants in significant quantities. Some of these (e.g. SO_2 , HCl) form acidic solutions in water, while SO_2 and others (e.g. NO , NO_2) are, as will be shown later, capable of being transformed into acids (SO_2 into H_2SO_4 , NO and NO_2 into HNO_3). It has also been demonstrated that these substances and their conversion products are capable of being carried by air movements for up to several days and hundreds of kilometres, with significant amounts still being deposited to the ground after that time.

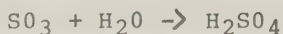
The concentrations of pollutants emitted by a typical, medium-sized power plant burning coal are shown in the table below. These figures assume that there are no control measures, except for particulate matter.

Typical Pollutant Concentrations
from a Coal-Fired Power Plant

<u>Pollutant</u>	<u>Concentration</u>
SO ₂	1100 - 1600 ppm
SO ₃	25 ppm
NO	300 - 700 ppm
NO ₂	30 - 70 ppm
HCl	100 ppm

(In-Stack Measurements : Source : Ontario Hydro, Lakeview Generating Station. These figures are typical. See for example Faucett et al (1977)).

Of these, HCl is a strong acid, while SO₃ is the anhydride of a strong acid. It reacts rapidly with water to form sulphuric acid.



Sulphur dioxide dissolves in water to form solutions of sulphurous acid, but it is also capable of atmospheric oxidation to sulphuric acid, which is a stronger acid. The oxides of nitrogen can be oxidised to nitric acid. These oxidation reactions will be considered in more detail below.

5.2 Chemical Transformation of Pollutants

5.2.1 Reactions of SO₂

5.2.1.1 Homogeneous Reactions

The homogeneous, gas phase reactions of sulphur dioxide have been extensively studied and are reasonably well understood (Calvert, 1981). The subject has been reviewed by Calvert et al (1978) and the reactions and their rates have been analysed by Moller (1980), who has indicated the most important paths.

During daylight hours free radical reactions predominate. The major role of the hydroxyl radical is now well established, and the rate constant for its reaction with SO₂ is known (see, for example, Moller, 1980; Calvert et al, 1978; Calvert, 1981). Direct measurements of OH radical concentrations have recently become possible (Campbell et al, 1979; Perner et al,

1976; Ehhalt et al, 1981; Killinger and Wang, 1977; Wang et al, 1974, 1975 and 1981; Davis et al, 1976, 1979a, 1979b, 1981), and the combination of the rate constant with the concentration produces the result that the rate of SO_2 oxidation by this path can be up to about $3.6\% \text{ hr}^{-1}$.

Other important homogeneous reactions of SO_2 are with the species which may be summarised as RO_2 , particularly alkyl peroxy radicals and Criegee intermediates resulting from the reaction between ozone and alkenes. A quantitative evaluation of the rate constants for these systems is not yet available - the mechanisms are complex, and subject to competition from other species, such as NO - but it is believed that they are capable of making a significant contribution to the overall rate (Calvert, 1981).

At night the concentrations of photochemically produced species drop to very low levels (for example measured concentrations of OH are 10 to 50 times lower than day time values). However, the Criegee intermediates will persist as long as ozone and olefins are present.

5.2.1.2 Heterogeneous Reactions

Sulphur dioxide is very soluble in water (more than 20 g per 100 g water at 0°C), so aqueous phase reactions of SO_2 are important, e.g., in clouds, fog, aqueous films on airborne particulate matter, etc. Since a significant fraction of cloud droplets are formed by condensation on solid nuclei, catalytic effects are possible in clouds as well as on aerosol particles.

Martin and Damschen (1981) have studied the solution chemistry of SO_2 , and find that oxidation is fast by hydrogen peroxide but somewhat slower by ozone. Hydrogen peroxide in high concentrations has been measured in rainwater by Kok (1981). His results also indicate that hydrogen peroxide can be formed by bubbling polluted air through water, i.e., it is capable of continuous replenishment in cloudwater. The mechanism of formation is not yet known, but it is suspected that ozone is involved.

Sulphur dioxide is oxidised by atmospheric oxygen in the presence of catalysts. Martin (1981) has indicated that iron and manganese are catalytically active, and that they are synergistic in combination, but that various forms of vanadium, copper, cobalt and lead do not catalyse the reaction.

It is known that aqueous phase oxidation by the nitrite ion is possible, but atmospheric concentrations are probably too low for this to be a significant pathway (Durham and Demerjian, 1981).

The rates of the liquid phase reactions will be very highly variable, since they depend strongly on temperature, the concentrations of catalysts, reagents, SO_2 and cloud or rain water, as well as on the acidity of the water (which affects the solubility of SO_2 , and also appears to catalyse the reaction with hydrogen peroxide). To underline the possible importance of these reactions, Martin has calculated from his results that in a cloud with 1 ppb of H_2O_2 and 0.3 ml water per cubic metre, the rate of sulphate formation could be as high as 3% per minute. This is very much higher than has ever been observed, presumably because the rate very rapidly becomes limited by local depletions of reagent.

5.2.1.3 Field Studies

A considerable number of field studies have been carried out on the conversion of sulphur dioxide to sulphates. Some of the results, i.e., those pertaining to urban plumes, have been reviewed by Alkezweeny (1980) and were found to range from 0.28 to over 30% hr^{-1} . His own results, carried out as part of the MAP3S Study, lay in the range 0 to 4% hr^{-1} .

Newman (1980) has reviewed measurements of SO_2 oxidation rates in power plant and smelter plumes. The results generally lie in the range below about $4\% \text{ hr}^{-1}$, and the rates are highest during periods of maximum solar intensity. It is tempting to interpret this as reflecting photo-chemical activity, but it could merely be a consequence of atmospheric mixing being enhanced by solar radiation heating.

Eatough et al (1980) measured SO_2 oxidation in the Great Basin Desert region, and on the California Coast, and found that the rate varied between 1 and $6\% \text{ hr}^{-1}$. This rate apparently increases with increasing temperature.

Forrest, Garber and Newman measured daytime SO_2 oxidation rates of 1 to $4\% \text{ hr}^{-1}$ in the plume of an oil-fired power plant (Garber, Forrest and Newman, 1980). Rates at night were 5 to 10 times lower than those measured during the day.

Whitby et al (1980) found SO_2 oxidation rates ranging between 0.1 and $8\% \text{ hr}^{-1}$ for plumes from five power plants, while a 24 hour average rate of $0.18\% \text{ hr}^{-1}$ was found by Williams et al, (1980) for a smelter plume in a remote region of Australia. Gillani et al, (1980) have studied project MISTT data, and have been able to parameterise the observed conversion rates in terms of atmospheric reactivity and mixing and solar intensity.

These reported oxidation rates for SO₂ are summarised in the following table:

Measured Oxidation Rates for Sulphur Dioxide (% hr⁻¹)

<u>Range</u>	<u>Location</u>	<u>Reference</u>
6 - 25	Rouen, France	a
1.2 - 13.0	Los Angeles	b
31	Budapest, Hungary	c
10 - 14	St. Louis	d
8 - 11.5	St. Louis	e
5.3 - 32	St. Louis	f
<4	St. Louis	g
0 - 6.8	Milwaukee	h
0.6 - 4.4	Arnhem-Amsterdam, Netherlands	i
0.28 - 1.73	W. Europe	j
1.1	Faroe Is. & British Isles	k
0 - 3	British Isles	l
0.73	Ohio Valley	m
1.0 - 5.0	St. Louis	n
0	Gary	
0 - 5	Labadie	o
0.5 - 3	Labadie	p,q
0.5 - 3	Alberta	r
1 - 2		s
1 - 6	Pennsylvania	t,u,v

"A few tenths

to a few percent"

		w
0 - 5.7	W. & Mid-West U.S.A.	x
1 - 3	Sudbury, Ontario	y
<0.5	Sudbury, Ontario	z
1 - 6	Great Basin Desert, California	bb
1 - 4	Cumberland	cc
<1	Northport	dd
0.1 - 8.0	Minnesota, Alabama, Tennessee,	
	Missouri, Arizona	ee
0.18	Australia	ff
<3 - 10	Labadie, Cumberland, Johnsonville	gg
<2	Florida	hh

References

- a) Benarie et al, (1972)
- b) Robert & Friedlander (1975)
- c) Meszaros et al, (1977)
- d) Alkezweeny & Powell (1977)
- e) Alkezweeny (1978)
- f) Breeding et al, (1976)
- g) Forrest et al, (1979a)
- h) Alkezweeny et al, (1977)
- i) Elshout et al, (1978)
- j) Eliassen and Saltbones (1975)
- k) Prahm et al, (1976)
- l) Smith & Jeffrey (1975)
- m) Lavery et al, (1979)
- n) Alkezweeny (1980)
- o) Husar et al, (1976)
- p) Husar et al, (1978a)
- q) Gillani et al, (1978)
- r) Lusi et al, (1978)
- s) Meagher et al, (1980)
- t) Diffenhoeffer & De Pena (1978)
- u) Diffenhoeffer & De Pena (1979a)
- v) Diffenhoeffer & De Pena (1979b)
- w) Hobbs et al, (1979)
- x) Hegg & Hobbs (1980)
- y) Lusi & Wiebe (1976)
- z) Chan et al, (1980)

- aa) Newman (1980)
- bb) Eatough et al, (1980)
- cc) Forrest, Garber & Newman (1980)
- dd) Garber, Forrest & Newman (1980)
- ee) Whitby et al, (1980)
- ff) Williams et al, (1980)
- gg) Gillani et al, (1980)
- hh) Forrest et al, (1979b)

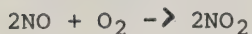
It can be seen that the later results show far less variation than the early ones, which possibly reflects improvements in experimental methods. What variability remains in the latest results can possibly be ascribed to variations in the heterogeneous oxidation rates, although the cause may lie in the problems which still remain with the interpretation of the field study data, particularly for the case of urban plumes. Thus, it can be said that the atmospheric oxidation reactions of sulphur dioxide, particularly the homogeneous ones, are reasonably well understood, although some of the fine details still require clarification.

5.2.2 Reactions of NO_x

5.2.2.1 Homogeneous Reactions

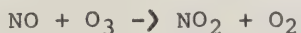
The gas phase chemistry of the oxides of nitrogen has been extensively reviewed by Demerjian et al, (1974). More up to date rate constant values may be obtained from detailed compilations, e.g., Hampson & Garvin (1977), Baulch et al, (1980).

The predominant oxide of nitrogen formed during combustion processes is nitric oxide, NO. As long as the concentration of this species is above a few hundred parts per million, it is oxidised at a significant rate by atmospheric oxygen.



However, the rate of this reaction depends on the square of the nitric oxide concentration, and rapidly becomes negligible as the emitted pollutants become diluted by mixing into the atmosphere.

In a well defined plume, such as that from a power plant, the major path for oxidation of NO is by reaction with background ozone in the ambient air.



The rate of this reaction is determined primarily by the rate at which the ozone mixes into the plume (Melo, 1980; Forrest et al, 1980).

Over an area source, where there will normally be a mix of more or less aged pollutants, oxidation is also effected by hydroperoxy and alkyl peroxy radicals.

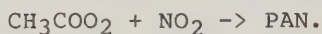


By comparison with the case of SO₂, these reactions are fast, and most of the NO will normally be converted to NO₂ in a few hours (during daylight hours).

The main subsequent oxidation reactions of NO₂ involve formation of nitric acid, by



and formation of peroxyacetyl nitrate (PAN) by



The relative probabilities of these two channels depends mainly on the concentration of hydrocarbons (Spicer, 1979); PAN can not be formed if hydrocarbons are absent.

The final ratio of organic to inorganic nitrates depends on temperature, since the rate of the dissociation of PAN is highly temperature dependent, becoming rapid above about 25°C (Hendry & Kenley, 1979). The NO₂ thus created has a finite probability of being converted to nitric acid, rather than to another molecule of PAN, and the net effect is that PAN tends to be recycled through NO₂ to HNO₃.

Again these reactions are rapid by comparison with the case of SO₂. The rate constant for the reaction between OH and NO₂ (Anastasi et al, 1976) is ten times as large as that for OH plus SO₂ (Calvert et al, 1978).

5.2.2.2 Heterogeneous Reactions

Apart from the reactive dissolution of NO₂



(Orel and Seinfeld, 1977; Middleton and Kiang, 1979; Lee and Schwartz, 1981), almost nothing is known about the heterogeneous reactions of the nitrogen oxides, although some reactions must occur.

However, because the homogeneous reactions of NO and NO₂ are so rapid, it is often assumed that the heterogeneous reactions are not competitive.

5.2.2.3 Field Studies

Very few field studies have been carried out on the oxidation of nitrogen oxides, mainly because it has only recently become possible to make accurate measurements of nitrate concentrations. Richards et al (1980) commented on this difficulty and suggested that NO_x oxidation rates are most easily obtained by assuming that they are faster by a constant factor than the SO₂ rates. This factor would be in the range of 4 to 7.

Forrest et al, (1980) measured the rate of conversion of NO to nitrates in the plume of the Cumberland Power Plant, and found that it lay in the range 3 - 12% hr^{-1} . Because the oxidation of NO to NO_2 is normally rapid compared with the subsequent step, their measured rate approximates the oxidation rate of NO_2 .

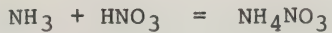
Spicer (1977) derived a conversion rate of approximately 10% hr^{-1} for NO_2 in the Los Angeles area, while a lower limit of 12% hr^{-1} was obtained in the Philadelphia urban plume (Spicer and Sverdrup, 1979). However, the most reliable result is probably the 17% hr^{-1} measured for the Boston urban plume (Spicer, 1979).

5.2.3 Neutralization of Acids

Ammonia is a natural component of the earth's atmosphere, being present in rather varying concentrations, which average out to about 6 ppb. The source is chiefly bacterial action in soils (McConnell, 1973) and it is also produced anthropogenically.

The gas phase reaction between ammonia and strong acids such as H_2SO_4 and HNO_3 is very rapid, leading to neutralization of the acids. The extent of neutralization depends on the relative

concentration of the acids and the ammonia, and also on how rapidly atmospheric mixing will restore local depletions of ammonia. As a further factor, the reaction between ammonia and nitric acid does not go to completion, and an equilibrium state is reached,



where free nitric acid remains in the gas phase. The position of the equilibrium is highly temperature dependent, with more free acid being present at high temperatures (Stelson et al, 1979; Tang, 1980). Neutralization of atmospheric acids can also take place on air borne dust, which is often calcareous.

However, although the potential exists for the neutralization of free acids, it appears that this does not necessarily go to completion. For example, an analysis of the MAP3S rain chemistry measurements (Baker et al, 1981) indicates a strong correlation between acidity on the one hand and sulphate and nitrate concentration on the other. This indicates the coexistence of H^+ and SO_4^{2-} and H^+ and NO_3^- , i.e. the existence of free nitric acid, and, at least, acidic bisulphate salts, if not free sulphuric acid.

Stevens et al, (1980) characterised the atmospheric aerosol in the Great Smoky Mountains and found that 61% of the mass of the fine fraction comprised sulphates. Although the exact percentage of sulphuric acid and ammonium sulphate in these aerosols is not known, the average composition of these sulphates can be considered to be equivalent to ammonium bisulphate, which is acidic. Thus, wet deposition of these aerosols will result in acidic precipitation.

In fact, whether or not atmospheric acids are neutralized by ammonia may be academic, since Spicer et al (1980) have suggested that biological activity in soil and water may convert ammonium salts back to acids with evolution of ammonia.



(A Brief Review of the Tropospheric Chemistry of Sulphur Dioxide and the Nitrogen Oxides by J.S. Calvert is located in Appendix 6.)

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6. ATMOSPHERIC DEPOSITION

Atmospheric deposition may be divided into two broad categories - wet deposition, which includes all pollutant material reaching the earth's surface in precipitation; and dry deposition, caused by the processes of absorption of particulate and gaseous material by land and water surfaces.

6.1 Wet Deposition

Gaseous and particulate matter can be removed from the atmosphere by interaction with precipitation (rain or snow) either within the clouds (this is commonly called "rainout") or below the clouds (termed "washout").

Both in rainout and washout, particles are captured by droplets by impaction and interception, Brownian diffusion and various electrical and phoretic mechanisms. In addition, hygroscopic particles, such as those containing sulphates and nitrates, can act as cloud condensation nuclei, and the rainout of these nuclei is now thought to be one of the major contributors of sulphur in precipitation (see, for example, Garland, 1978). Gases are removed by diffusion and absorption by precipitation droplets. Absorption may be followed by chemical transformation, as in the case of sulphur

dioxide, where there is now some evidence that in-cloud oxidation processes may be another large contributor (in addition to nucleation of particulates) to the sulphates found in precipitation (Hales and Dana, 1979b; Scott, 1980).

Mathematical modellers have usually parameterised the atmospheric wet deposition of particulate matter and gases either in terms of a scavenging coefficient or a washout ratio (e.g., see Dana, 1979). The former results from the assumption that wet deposition is an exponential decay process (since particles and gases are repeatedly exposed to cloud or precipitation elements, with some chance of being scavenged during each exposure) obeying the equation:

$$C_t = C_0 \exp (- \lambda t) \quad (1)$$

where:

C_t = concentration of scavenged material at time t

C_0 = its initial concentration

λ = scavenging coefficient

The washout ratio is defined as the concentration of contaminant in precipitation divided by its concentration in air (usually at the surface level), i.e.,

$$W = X/C$$

where:

X = concentration of contaminant in precipitation

C = its concentration in air

W = washout ratio.

The two parameters λ and W are related. For example, for the simple case of pollutant washout from a column of air having a uniform concentration over height h, one obtains:

$$\lambda = WJ/h$$

where:

J = the precipitation intensity.

Therefore, in the following discussion, attention will be focussed on the scavenging coefficient, since most of the conclusions can also be applied to the washout ratio.

The scavenging coefficient depends on a number of meteorological parameters as well as the chemical and physical properties of the material scavenged. It is generally agreed that the precipitation rate and its characteristics (rain or snow) are important in determining the value of λ , as are also the size distribution and chemical properties of the particles scavenged, and the solubility of gases (including its variation with temperature and acidity of the absorbing droplet). (See, for example, Engelmann, 1968; Slinn, 1977 and 1981; and Hales, 1978.) Although attempts have been made to predict the scavenging coefficient theoretically, the mathematical modeller must still look to experimental data whenever possible, since theoretical predictions (especially for particulates) may not be better than an order-of-magnitude (See, e.g., Slinn, 1977).

The table below shows most of the available experimental data on λ for sulphur and nitrogen oxides. Note the strong dependence of scavenging rate for SO_2 on the precipitation type and intensity, as indicated by the experiments of Summers (1977). Part of the large observed variability in λ for SO_2 can no doubt also be attributed to the dependence of SO_2 solubility on the acidity of the absorbing raindrops (Hales, 1978; Hales and Dana, 1979a; Barrie, 1981). There is little data available on wet deposition rates of sulphates or the nitrogen compounds. A compilation of the data on

scavenging of particles in a similar (submicron) size range to sulphates, by rain and snow, shows that most of the available λ values fall within a factor of two or three of 10^{-5} s^{-1} (Lusis and Shenfeld, 1981). It should be noted that for hygroscopic particles such as sulphates and nitrates, the scavenging rate may also strongly depend on the mechanism of precipitation formation (Scott, 1978, 1981).

Experimental Data on Scavenging Coefficients
for Sulphur and Nitrogen Oxides

<u>Source</u>	<u>$\lambda (10^5 \text{ s}^{-1})$</u>	<u>Comments</u>
Kalstein <u>et al.</u> , (1959)	2	Rainout and washout of SO_4 and NO_3 .
Beilke (1970)	$17 J^{0.6}$	Laboratory washout results for SO_2 $\text{NO}_2 = 1/4 \text{ SO}_2$
Makhonko (1967)	6	Field data for SO_2
Dana <u>et al.</u> , (1975)	0.1 - 2	Washout of SO_2 from generating station plume. Strong dependence on raindrop acidity.

Summers (1977)	3J	Based on field data - rainout of SO ₂
	0.1J	Based on field data - snowout of SO ₂

Note: J = rainfall rate, mm h⁻¹

6.2 Dry Deposition

Particles and gas can be dry-deposited at the earth's surface by a number of mechanisms including impaction, gravitational settling and Brownian diffusion (for particles) and molecular diffusion followed by absorption (for gases). For both particles and gases, turbulent diffusion within the boundary layer plays an important role in bringing material to the earth's surface.

The dry deposition rate has usually been estimated from the ambient concentration of the substance of interest using a parameter called the "deposition velocity", which is defined by the equation:

$$F = vc$$

where:

F = the flux of material to the surface

c = its ambient concentration

v = the deposition velocity

The deposition velocity is an experimentally determined parameter, and should refer to the same height as the concentration measurement. It is interesting to note that not only has the deposition velocity approach been generally adopted by mathematical modellers, but a recent EPA workshop on dry deposition rate measurement methods also concluded that, until reliable methods suitable for direct field monitoring of dry deposition are developed, the use of this approach is the only presently available alternative that is practical and sufficiently accurate (Hicks et al., 1980).

The deposition velocity depends on meteorological parameters such as atmospheric stability and wind speed; on surface characteristics (such as surface roughness, and type of surface) and on the physical and chemical nature of the substances deposited. (See, for example, discussions in Wesely and Hicks, 1977; Sehmel, 1980.) The following table shows some of the experimental results for deposition velocity of sulphur and nitrogen oxides.

Experimental Data on Dry Deposition Velocities
for Sulphur and Nitrogen Oxides

<u>Source</u>	<u>v (cm s⁻¹)</u>	<u>Comments</u>
Chamberlain (1979) Husar <u>et al.</u> (1978b)	0.4 - 0.8	SO ₄ over a variety of plants and soils, water. May be somewhat lower (0.1 - 0.2) for snow.
Garland (1978) Droppo (1979)	< 0.1 0.1 - 0.3 Negative	SO ₄ over grass. SO ₄ over arid vegetation. SO ₄ daytime, non-arid vegetation (i.e., surface source)
Sievering <u>et al.</u> (1979)	0.2	SO ₄ over water.
Everett <u>et al.</u> (1979)	1.4	SO ₄ over slightly rolling grassland.
Ibrahim <u>et al.</u> (1980)	0.1 - 0.2	Ammonium sulphate aerosol over snow. (Note: the aerosol size distribution was bimodal with much of the material deposit-

		ed from the mode with 10 micron mass median diameter).
Judeikis and Wren (1978)	0.3 - 0.8	NO ₂ over soil, cement surfaces.
Sehmel (1980)	1.9	NO ₂ over alfalfa canopy.
Judeikis and Wren (1978)	0.1 - 0.2	NO over soil, cement surfaces.
Sehmel (1980)	0.1	NO over alfalfa canopy.

Keeping in mind the material presented above as it relates to atmospheric chemistry and deposition, we wish to discuss model parameterization before entering into a specific discourse related to the MOE-LRTAP model.

Our understanding of the dry deposition of sulphur dioxide is relatively good. For a wide range of surfaces, including vegetation, water and soils, the deposition velocity has been found to be typically in the range 0.4 to 0.8 cm s⁻¹. For snow surfaces, the value is somewhat lower (0.1-0.2 cm s⁻¹). A comparison of the deposition velocities of SO₂, NO₂ and NO on similar surfaces suggests that values for NO₂ are somewhat smaller than those for SO₂ - roughly one-half as great -

while those for NO are less than one-tenth as great (Judeikis and Wren, 1978; Sehmel, 1980).

The dry deposition rate of sulphates is not as well understood as that for SO₂, and there is at present some confusion about deposition velocities of particles in the 0.1 - 1.0 micron size range (where most of the sulphate mass is expected to occur). Lusis and Shenfeld (1981) have supplemented the deposition velocity values for sulphates shown in the table above with others observed for substances such as lead (which occurs in a similar particle size range), and have found that for smooth surfaces, such as snow or water, the particle deposition velocity is small - less than about 0.2 cm s⁻¹. For rougher surfaces, the available data range from less than 0.1 cm s⁻¹ (including a number of negative values) to velocities comparable to those for SO₂ (Sheih et al., 1979). Theoretical predictions for submicron particles suggest that for relatively smooth surfaces v should not be much greater than 0.1 cm s⁻¹ (see, for example, Sehmel and Hodgson 1978; Ibrahim et al., 1980), but considerably greater values are possible for rough surfaces such as vegetation (Davidson et al., 1981). Nevertheless, more experimental data is needed to clarify some of the contradictory measurements on sulphate dry deposition rates. Also, as can be seen from the table, no data are currently available on dry deposition rates for particulate nitrates and nitric acid.

References - Chapter 6

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7. PARAMETERISATION OF ATMOSPHERIC PROCESSES IN CURRENT MODELS

In the Federal Register of Friday, May 1, 1981 it is stated that the EPA would "...welcome comments and testimony on the availability and use of long range models...." Several long range transport models are now being developed and utilized by a number of groups or agencies. In order for these models to be operational, such items as atmospheric chemistry and deposition need to be parameterised. The previous two chapters have summarised Ontario's present knowledge of atmospheric chemistry and deposition and this chapter describes the parameterisation of long range transport models presently in use to describe S transport from source to receptor areas. As pointed out below, these models deal only with sulphur emissions transport, chemistry and deposition. It is important that the models consider all forms of sulphur and that this problem cannot be approached by addressing SO₂ alone. When looking at source-receptor relationships, the complete SO₂-SO₄ picture must be studied.

The atmosphere is a very complicated system, yet most of the current models for long range transport attempt to parameterise chemistry and deposition by simple, linear rate laws (either explicitly or implicitly). Attempts at more complex (and realistic)

development, and testing and validation of such models will require time, probably several years. Ontario is thus confronted with the dilemma of having to make decisions, before irreversible environmental damage occurs, using admittedly imperfect modelling tools.

In fact, the parameterisations used for wet and dry deposition rates have some theoretical basis (see, for example, Engelmann, 1968; Slinn, 1977), and are generally accepted by the scientific community, with the proviso that more experimental information is needed to define better the values of these parameters under different meteorological conditions (and possibly also for different geographical areas).

On the other hand, the incorporation of atmospheric chemistry into current models merits further discussion, which will be illustrated by reference to the five models listed below:

Representative Current Long Range Transport Models

<u>Name</u>	<u>Reference</u>
ASTRAP	Shannon, 1981
ENAMAP	Bhumralker <u>et al</u> , 1980
RCDM	Niemann <u>et al</u> , 1980; Fay and Rosenzweig, 1980
AES-LRT	Voldner <u>et al</u> , 1980
OME-LRT	Venkatram <u>et al</u> , 1980

These models were singled out because of their identification by Work Group 2 as set up according to the U.S.-Canada Memorandum of Intent on Transboundary Air Pollution. They are representative of current modelling efforts, and are presently in a running state.

None of these models considers the chemistry of the nitrogen oxides at all, while they all treat the chemistry of SO_2 as being first order. With the exception of ASTRAP, a constant value of the rate coefficient is employed, the value being such that the diurnally averaged conversion rate of SO_2 is approximately $1\% \text{ hr}^{-1}$. ASTRAP is more realistic in using a diurnally and seasonally varying rate coefficient.

Clearly the treatment of atmospheric chemistry is not complete, and critics of current modelling efforts, and the use of these in deriving source-receptor relationships and in evaluating control strategies, have not been slow to point this out. The result has been an understandable confusion on the part of legislators, scientists not working in the atmospheric sciences and the general public. The question, which is addressed below, is whether or not current models can provide usable information, even though they treat the chemistry in such a simple fashion.

Obviously the models will be improved if the chemistry of the nitrogen oxides is included, but in justification it should be noted that significant direct interaction of SO_2 and NO_x does not occur in the atmosphere (Calvert et al., 1978), although there is some indirect interaction by virtue of the role of NO and NO_2 in the photochemical generation of species such as OH, HO_2 , and alkylperoxy radicals which are important in the oxidation of SO_2 . However, NO and NO_2 are also competitors for these species, so that increased production is somewhat offset by increased consumption. Thus, particularly when it is remembered that NO_x is emitted in smaller quantities than is SO_2 , the neglect of NO_x chemistry does not invalidate the SO_2 chemistry that is included. However, since NO and NO_2 are transformed into acidic species (HNO_3) and aerosol particles, it is apparent that current models will tend to underestimate the impacts on receptors in terms of factors such as acid rain and visibility impairment. As a result of this conservative aspect, the models are suitable for regulatory or guideline use since such an application would not result in source over-regulation.

The use of a linear rate law for the oxidation of SO_2 has also received considerable criticism, and it is therefore instructive to consider the various oxidation reactions of SO_2 .

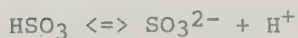
The major homogeneous pathway is reaction with OH, while reaction with species summarised as RO_2 will become important under polluted conditions. These processes have been convincingly demonstrated in numerous laboratory studies to be first order (see Calvert, 1981).

The catalysed aqueous phase oxidation of SO_2 by atmospheric oxygen has been critically reviewed by Durham and Demerjian (1981). They found that in many experimental studies the experimental conditions were not appropriate to those pertaining in the atmosphere, or were otherwise not sufficiently well characterised for meaningful conclusions to be drawn. Of the three studies on manganese catalysis which passed their assessment, two were consistent with a zero order reaction with respect to tetravalent sulphur, S(IV) , while the third indicated a first order dependence.

Durham and Demerjian (1981) also reviewed the oxidation catalysed by iron. In this case, three studies are in agreement with a reaction first order in S(IV) .

There also appears to be some uncertainty concerning the rate law for the aqueous phase oxidation of SO_2 by hydrogen peroxide. Penkett et al (1979) found that this reaction is first order with respect to HSO_3 , while Martin and Damschen (1981) found a first order dependence on $\text{SO}_2 \cdot \text{H}_2\text{O}$, i.e., dissolved sulphur dioxide.

The following equilibria are set up when gaseous SO_2 encounters water



where the third step can be neglected for the normal pH values encountered in clouds, fogs, rain, etc. It follows that the dissolved SO_2 concentration is directly proportional to the gas phase concentration, while the bisulphite ion concentration depends on the square root of the gas phase SO_2 concentration. The concentration of S(IV) in the liquid phase, being the sum of dissolved SO_2 and bisulphite, is thus also not strictly linear in gas phase SO_2 .

However, a comparison of the rates expected for the strictly first order homogeneous reactions (i.e., up to at least $3.6\% \text{ hr}^{-1}$) suggests that in many cases the former will dominate in the conversion of SO_2 . The overall rate law will therefore be approximately first order with respect to SO_2 concentration, unless unusual circumstances, e.g. a plume containing substantial concentrations of manganese, result in one of the

non-linear processes dominating the reaction. Thus, the oxidation of SO_2 can usually be approximated by

$$\frac{d[\text{SO}_2]}{dt} = k[\text{SO}_2]$$

where the rate coefficient, k , is given by

$$k = k_{\text{OH}} + k_{\text{RO}_2} + k_{\text{Mn}} + k_{\text{Fe}} + k_{\text{H}_2\text{O}_2}$$

This should not be interpreted as suggesting that the rate coefficient has a constant value. In fact, the converse is true, as can be seen by considering the individual contributions to k .

The value of k_{OH} depends directly on the concentration of hydroxyl radicals. Direct measurements of these concentrations have recently become available (Campbell et al, 1979, 1981; Perner et al, 1976; Wang et al, 1974, 1975, 1981; Davis et al 1976, 1979a, 1979b, 1981; as discussed by Calvert, 1981). It might be expected that these concentrations would depend strongly on the presence of pollutants such as NO_x and hydrocarbons in the air, but this turns out not to be the case. For polluted air at 40°N latitude, the peak concentration of OH appears to be about 9×10^6 radicals per cm^3 , while for rural air the value is about $8 \times 10^6 \text{ cm}^{-3}$ (Calvert, 1981). The reason for this relative

is that while the pollutants accelerate the production of OH, they also accelerate its removal, thus maintaining the balance (Durham and Demerjian, 1981).

The concentration of OH is, however, very strongly dependent on solar radiation intensity, as is evidenced by the difference between the peak summer concentration ($9 \times 10^6 \text{ cm}^{-3}$), peak winter concentration ($2.4 \times 10^6 \text{ cm}^{-3}$), and night time concentration ($2 \times 10^5 \text{ cm}^{-3}$) (Calvert, 1981). It is thus clear that the formulation of ASTRAP (diurnal and seasonal variation of the rate coefficient) is more realistic than that of the other models.

The magnitude of k_{RO_2} depends on the concentrations of the species RO_2 , which will depend in turn on the particular mix of pollutants being studied, with the hydrocarbon composition being particularly important.

It appears that the rate coefficients for the catalytic oxidation of SO_2 , i.e. k_{Mn} and k_{Fe} , depend sensitively on not only the catalyst concentration, but also on pH, while $k_{\text{H}_2\text{O}_2}$ depends on hydrogen peroxide concentration, and on pH.

However, although four of the five terms contributing to the pseudo first order rate coefficient for SO_2 oxidation show dependence on the precise composition of

the air parcel in question, there is still justification for accepting the validity of the simple formulation adopted in current models.

In the situation of long range transport the reaction between OH and SO₂ is expected to predominate as has been discussed above. This is partly because it is a rapid reaction, but is also due to the fact, previously noted, that OH radical concentrations remain approximately constant, while the concentrations of the other, pollutant derived, reactants will tend to decrease during transport as the plume dilutes. A substantial contribution to the rate coefficient is thus relatively independent of atmospheric composition.

The elimination of diurnal and seasonal variation of the rate coefficient, as used in five of the six models can only be justified for application to long times, when considerable averaging occurs. Therefore, in the present controversy, a distinction should be made between long-term, and event models. On an event basis, there can be a large variation in transformation and deposition rates (as is suggested by the discussion above and by some of the data presented in the previous chapters), and the interpretation of long range transport episodes, as well as their modelling, is a very difficult undertaking, requiring a considerable level of detailed knowledge about the history of the air parcel under consideration -

knowledge, which is often not available. On a long-term basis, however, many of these fluctuations are smoothed out, and the interpretation of long-term data is relatively simple compared to that of event data. The situation is somewhat analogous to the analysis of air quality monitoring data around a local point source. During a particular hour, a given downwind monitoring station may be measuring background concentrations, even though fumigations may have been strongly expected (the fumigation may have been occurring nearby, where no monitor was present); on the other hand, over a longer period of time, the average concentrations determined by the monitoring network should clearly indicate the effects of the point source on the local area.

Thus, comments will be confined to long-term model predictions. In these, "representative" atmospheric transformation and deposition rates can be used, based on the considerable body of available experimental and theoretical data. If the parameters are viewed in this way, then for an assessment of current source-receptor relationships, arguments about whether or not certain processes are accurately linear become largely academic, provided that assessment is restricted to the current situation. That is empirical data on transformation rates, determined under a wide variety of meteorological and geographical conditions is being used to calculate the fate of substances of interest. This empirical data

should be valid if there have been no marked changes in emission characteristics or meteorological processes since the time of the measurements. Thus the model predictions regarding the current impact of a particular source area on a particular receptor, on a long-term basis will be valid (of course, there is a margin of error associated with model predictions, because the understanding of atmospheric processes is still not complete). Also, various degrees of refinement are possible, even in models which deal with atmospheric processes in a simple way, such as the incorporation of diurnal, seasonal and geographical differences in the model parameters. The more refined models will improve the accuracy of predictions, but in many cases the necessary empirical data are still not available.

Care must be exercised when using models for predicting the consequences of changing the rates of emissions, or their composition - i.e., for control strategy evaluation. Ontario is satisfied that its long range transport model gives a good picture of the present situation. The indications are that the present sulphur loadings in Ontario are too high by a factor of 2 or 3. Ontario has parameterised the model with the best available information in order that it gives, "a best estimate", of the present source-receptor relationships. Although the model is not necessarily accurate enough to define the final regulatory decision, it is felt that it

can strongly indicate where money and effort should be best expended to control sources which would then result in the greatest benefit to sensitive receptor areas.

Ontario feels that if stepwise source reduction were considered, the model could reasonably project the qualitative picture of the loading changes, in spite of the linear nature of the parameterisation of the chemistry. Calvert in his summary of his review of The Tropospheric Chemistry of Sulphur Dioxide and the Nitrogen Oxides (See, Appendix 6, pg. 25) states that "...Until such time that more definitive experimental and theoretical treatments of the heterogeneous pathways can be made, it will be necessary to use some form of empirical parameterization of these processes in modelling attempts. Such methods cannot be of lasting value, and predictions based upon them will necessarily be of uncertain usefulness in development of predictive models and control strategies for 'acid rain'...."

Ontario therefore realizes that caution must be exercised in the use of the long range transport model and as a result, confidence limits are carefully considered when the model is utilized. This is why stepwise reductions are recommended as a first cut at reducing the total sulphur loadings in areas such as New York, Pennsylvania and Ontario. The way in which this is accomplished is discussed in detail in Chapter 10 for a recent situation in which an aggregation of SO_2 sources

in Ontario were controlled.

In summary, it can be said that the homogeneous gas phase reactions of SO_2 and NO_x are now fairly well understood, while a start has been made on unravelling the complexities of the heterogeneous reactions of these species. Although these processes are known to be complex, mathematical models in current use make the drastic simplifications of omitting NO_x chemistry completely, and incorporating SO_2 oxidation as a first order process with a diurnally and seasonally varying rate coefficient (ASTRAP) or with a fixed rate coefficient (ENAMAP, RCDM, AES-LRT and MOE-LRT). A detailed analysis of the chemistry reveals that for particular applications the utility of the models is not destroyed by these simplifications.

Current models emphasis SO_x chemistry because of the importance of sulphur compounds to impacts on the acid sensitive receptors. It has been pointed out by Work Group I of Canada/U.S. MOI that NO_3^- has relatively less impact on the sensitive receptors than $\text{SO}_4^{=}$. The relative importance of $\text{SO}_4^{=}$ and NO_3^- with regard to their impact on sensitive receptors is fully discussed in the Aquatic and Terrestrial impact chapters.

The conclusion is reached that current models are adequate for defining source-receptor relationships on a long-term, long range basis, but that they have not yet been developed to the stage where they can be applied with confidence to the study of single pollution episodes or to the derivation of source control strategies. It can be stated though, that the deposition of secondary pollutants (such as acidity) can be related to particular emission sources, and that a reduction in emissions will result in a reduction in deposition. A quantitative relationship between the two reductions is probably not yet available, but since current rates of deposition are damaging to the environment, it follows that, at the very least, emissions must not be increased.

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8. MINISTRY OF THE ENVIRONMENT MODEL

In his presentation at the June 19th Hearing, Dr. Gregg Van Volkenburgh talked about "What Modelling Tells Us About Ontario, New York and Pennsylvania Transboundary Air Pollution". In addition to his comments at that time, this submission includes, a detailed description of the MOE Statistical Long Range Transport Model. (See Appendix 7). This document describes the nature, development, assumptions, parameterisation, testing and application of this model. Appendix 8 is a report on a test of the model sensitivity to uncertainty in the value of the input parameters.

The MOE Model has been very useful to Ontario in predicting the long-term impact of source areas on eastern North America. It is a current state-of-the-art model and it is continually being modified and upgraded. It is presently being critically reviewed by Work Group II of the Memorandum of Intent. The Ministry of the Environment also commissioned peer reviews of this model and these comments are shown in Appendices 9, 10 & 11. Although the three reviewers were correct in pointing out several shortcomings or ways in which the model could be improved, the overall tenor of their comments was that the model was an acceptable way of predicting the deposition contributions of existing sources. A few of the comments are listed below:

"In summary, the MOE model is a highly efficient and useful method for predicting L.R.T.A.P., although it has some disadvantages and may lack important time resolution. Further development and verification of the model seems called for, but provided it is presented fairly and forthrightly it does seem to provide a reasonably good basis on which to argue Ontario's case to the American hearings."

F.B. Smith
Meteorological Office
Bracknell, England

"The MOE model, within its limits of accuracy, is a satisfactory method of assessing the sulfur deposition over Ontario from 20 U.S. power plants and for estimating changes in deposition produced by changes in emission."

Further work underway at the MOE and elsewhere may help to refine the model and the choice of parameter values used.

B.E.A. Fisher
Central Electricity
Research Laboratories
Leatherhead, England

"Ontario has provided an assessment analysis using a simplified statistically-based model. The model formulation accounts for the most important aspects of long range sulphur oxide transport including transformation and removal. These are simulated in a physically realistic manner consistent with models and assumptions of other investigators. The model clearly has limitations but gives reasonable estimates of levels of long-term pollutant concentrations and deposition values which are supported by limited verification studies. Sensitivity tests indicate that some variations in concentration and deposition patterns which the model is unable to simulate may cause significant deviations from the long-term mean values. These do not negate the value of the MOE estimates, but do show areas for model improvement."

D.J. McNaughton
North American
Weather Consultant
Salt Lake City, Utah

Ontario has therefore been encouraged in its model development, and is therefore trying to improve or upgrade its statistical model as well as work on the development of an event model to assist in the better evaluation of source-receptor relationships.

9. STANDARD SETTING IN ONTARIO

Before discussing Ontario's application of its long range transport model to the Province's major SO₂ emitters, below is provided a short summary of Ontario's methods for standard setting and the special application of legislation when it is deemed necessary for complex situations.

In Canada, the Provinces are responsible for managing their own air quality and Ontario has developed its own approach to ambient air management involving the use of ambient air quality objectives and point of impingement standards to prevent any adverse effects. The ambient air quality objectives (not ^{the} standards), are used to judge the impact of emission control programs. The point of impingement standards are modified emission standards for individual sources, and are set such that if everyone abides by them, the ambient air quality is satisfied. In setting these standards, cognizance is taken of the contaminant general background concentration, the importance of the contaminant, synergistic effects with other contaminants, and any other significant factors affecting the attainment of the desired air quality.

Provincial legislation involves the setting of comprehensive general regulations, but authority is also

given for handling special circumstances requiring more stringent standards. Where the application of a general standard does not result in good ambient air quality, studies are undertaken to determine the facts of the situation, and to set appropriate regulations to deal with the circumstances (e.g., a special regulation for the Sarnia area, the Air Pollution Index, and the sulphur in fuel regulation for Toronto).

This approach is similar to the U.S. offset policy in non-attainment areas, which calls for a reduction in contaminant emission from the existing plants in an area to allow for the emissions from a new operation coming into the area as well as involving an incremental improvement in ambient air quality. Ontario regulations, on the other hand, require that the reductions made by existing sources are sufficient to satisfy the ambient air quality criteria in the area, as well as making an allowance for the emissions from the new operation.

In Ontario, where a new source of contaminant emission is being considered in an industrial complex, it is normal practice to assess the overall emission of the contaminant from the whole complex in determining its compliance with the point of impingement standard. This is a procedure similar to the U.S. bubble policy which allows the company the flexibility of using the most cost-effective means of reducing contaminant emission,

provided the required total reduction is achieved for the complex as a whole.

However, more recently there has been concern regarding the adverse effects of acid deposition resulting from long range transport of contaminants. Although the ambient air quality criteria were essentially being met by INCO LTD. and ONTARIO HYDRO, special legislated regulations were promulgated requiring significant reductions in acid gas emissions. In the case of Ontario Hydro, this utility has the flexibility of choosing the sites for contaminant reduction as well as using the most cost-effective means of achieving the overall reduction. In other words, this is a broader application of the U.S. "bubble policy" as well as an example of a special regulation to deal with a specific pollution problem.

10. APPLICATION OF THE LONG RANGE TRANSPORT MODEL IN A MULTI-SOURCE ABATEMENT STRATEGY

10.1. Introduction

In this chapter it will be demonstrated how a long range transport model can, and has been, utilized to help develop an abatement strategy for aggregate sources. Using this technique, it is possible to estimate the effectiveness of various control strategies and then apply resources and efforts to abatement activities at the sources which would achieve the greatest relief for susceptible receptor areas. Although, in Ontario, this model application was carried out for acid rain abatement, the same principles can be used for control of sources of SO₂ and other pollutants.

The MOE-LRT model was utilized in the case of Ontario Hydro to develop source-receptor relationships. These relationships were used as one tool in determining the costs and benefits of specific control option scenarios.

The following is a description of how the model was applied to the task. The deposition rate of all forms of sulphur, D_i , at the i^{th} receptor is given by the following equation:

$$E_j T_{ji} = D_i \quad (1)$$

where E_j is the emission rate of sulphur at the j^{th} source. The quantity T_{ji} represents the physical relationship between the source j and the receptor i , and the summation is carried over repeated indices. The collection of values T_{ji} comprise a "transfer matrix". Equation (1) implies that atmospheric processes leading to the deposition of sulphur to the surface are linear. The validity of this assumption is discussed in Chapter 7 "Parameterization of Atmospheric Processes in Current Models", and was considered explicitly when the results of these scenarios were reviewed. It was felt, however, that the linearity assumption did not limit the usefulness of the model in this exercise.

There are several ways in which equation (1) can be applied to maximize a reduction in the deposition of sulphur to the receptor. One such method is to prescribe 'a priori' a deposition field which satisfies the constraint on the maximum permissible deposition to the receptors, and infer through equation (1) the emission field which satisfies this constraint. This gives the following:

$$E_j = D_i T_{ji}^{-1} \quad (2)$$

where D_i is the target deposition rates, E_j is the emission field meeting this target, and T_{ji}^{-1} is the inverse of T_{ij} .

A second approach is to use a linear programming method where constraints can be put on both D_i and the cost of reducing E_j to satisfy these D_i values. This is represented by the following:

$$\sum_j E_j T_{ji} < D_i \quad (3)$$

$$\sum_j E_j = \text{Maximum}. \quad (4)$$

Equation (4) assumes that cost is linearly related to the emission reduction. For large emissions reductions throughout a system, this assumption may break down, but for the extent of the system reductions which were contemplated in this exercise, the assumption generally holds true.

A third approach is to reduce emissions such that the reduction in deposition of sulphur at the receptor is maximised, subject to some constraints on the emissions. The objective function is now defined as:

$$\Delta D = \sum_j \sum_i \Delta E_j T_{ji} a_i \quad (5)$$

where ΔD is the reduction in D , ΔE_j is the reduction in E_j and a_i is a weighting factor depending on economics, existing damage, etc., related to a specific receptor. Equation (5) can be simplified to the following:

$$\Delta D = \sum_j \Delta E_j f_j \quad (6)$$

where

$$f_j = a_i T_{ji} \quad (7)$$

10.2 Application of the Model to Ontario Hydro

The strategy to reduce the SO₂ emissions from Ontario Hydro was developed from assessments done using the methods outlined above. The following discussion explains in detail how the various methods were applied.

10.2.1 Reductions Calculated According to Maximum Deposition Reduction in Sensitive Areas

These calculations involved maximising the reduction of deposition at sensitive receptors in the United States and Canada (Approach 3 in Section 10.1). The reduction of deposition, ΔD , was maximised given a set of constraints on the emissions at the six Hydro stations whose 1978 emissions are given below:

Name of Power Plant	1978 SO ₂ Emission Rates (tonnes/year)	Date Built	Expected Retirement Date	Maximum Possible Reduction (E _{ti}) (tonnes/year)
Nanticoke	183,870	1975	2007	165,483
Lambton	130,970	1970	2003	117,873
Lakeview	89,220	1966	1996	80,298
Lennox	21,297	1976	Now moth-balled	10,648
Thunder Bay	6,698	1970	1993	6,028
Hearn	3,637	1957	1988	3,273

The column on the right gives the maximum possible SO₂ emissions reduction (ΔE_{ti}) which could be achieved with the best available technology. Therefore any reductions (ΔE_i) would of necessity, have to be equal to, or less than, this amount. This information can be expressed by the mathematical statement:

$$\Delta E_i \leq \Delta E_{ti} \quad (8)$$

The Ministry of the Environment estimated the emission reductions (E_i) necessary to maximise D given that:

(1) $\sum \Delta E_i = 0.5 \times 1978 \text{ emissions (i.e., a 50\% emissions reduction across the fossil-fueled part of Hydro's system).}$

(2) $\sum \Delta E_i = 0.75 \times 1978 \text{ emissions (i.e., a 25\% emissions reduction across the fossil-fueled part of Hydro's system).}$

The environmentally sensitive receptor areas considered in computing ΔD were:

1. Muskoka-Haliburton, Ontario
2. Algoma, Ontario
3. Lakehead, Ontario
4. Val D'or, Quebec
5. Western Pennsylvania
6. Adirondacks, New York

Note that there are three sensitive receptors in Ontario, one in Quebec and two in the United States. The Ministry examined the emission reductions corresponding to several possible ways of assigning the weighting factors a_i in equation 7.

Scenario

Weighting

1. $a_1 = a_2 = a_3 = 1, a_4 = a_5 = a_6 = 0.0$

This weighting restricted the evaluation to Ontario

2. $a_1 = 3, a_2 = 1, a_3 = 1, a_4 = a_5 = a_6 = 0.0$

This weighting placed importance on protecting the Muskoka-Haliburton Region because of its economic importance and existing heavy loadings of sulphur.

3. $a_1 = 3, a_2 = a_3 = a_4 = 1, a_5 = a_6 = 0.0$

This arrangement considered Canadian areas.

4. $a_1 = a_2 = a_3 = a_4 = 1, a_5 = a_6 = 0.0$

This weighting considered Canadian areas equally.

5. $a_1 = a_2 = a_3 = a_4 = a_5 = a_6 = 1$

This arrangement considered all areas equally.

6. $a_1 = 3, a_2 = a_3 = a_4 = a_5 = a_6 = 1$

This arrangement considered all areas.

The transfer matrix elements T_{ji} were taken from the MOE statistical long range transport model, by considering the impact per unit area per unit time, for a unit emissions rate. Using the procedure described previously, ΔD was maximised for the six scenarios and two emissions rate reductions outlined above. The cost of each scenario was then computed, and costs versus benefits were intercompared.

The results of calculations using this approach allowed the Ministry to formulate the following conclusions:

- ° The largest reduction in deposition for all scenarios occurred when maximum emissions controls were placed on the smaller plants, and then to a slightly lesser extent on some of the larger plants.
- ° However, the cost of these scenarios was extremely high, because the smaller plants required a large capital investment to have control equipment or special fuels employed.

- ° If one reworked the calculations for each scenario using control at the largest three plants only, the cost was much lower, and the deposition reduction only slightly less. This situation occurred because the smaller plants were close to sensitive areas, but did not have a large amount of emissions. In other words, they were initially selected for control because of their damage per unit emissions. However, if one deleted them from the list of sources to be controlled, because the emissions were small, the absolute impact was small.
- ° The results of all scenarios indicated that control at the oldest large plant - Lakeview - was marginally more effective than at the two newer large plants - Lambton and Nanticoke. However, if control equipment (such as flue gas scrubbers) were employed, the cost of each scenario would be very large, because of the limited lifetime of the plant and the lack of room for the equipment. (Landfill into the lake, and special physical plant design would have been required to install such equipment.)
- ° However, where the scenarios were rerun with Lakeview excluded from control and only Lambton and Nanticoke included, the "environmental benefit", as measured by ΔD , achieved from a fixed amount of

emissions reductions at one or both plants, was nearly as large numerically as that of the "three plant" scenarios. Given the uncertainty level of the model, it was judged that the results were not significantly different. And the cost of these "two plant" scenarios was much lower than the cost of scenarios involving large scale control at Lakeview.

- ° The scenarios which considered Ontario sensitive areas only as the basis of control indicated that maximum emissions reduction at Nanticoke, followed by significant control at Lambton, achieved only 5 to 10 per cent more in deposition reduction than control instituted in the reverse order. This difference was judged not significant in view of the model's uncertainties.
- ° A similar result was obtained for these two plants for scenarios involving all Canadian, or all North American areas.
- ° The overall conclusion from applying this method was that if one applied a fixed amount of emissions reduction to either Lambton or Nanticoke, the costs were significantly lower than all other scenarios, and the amount of deposition reduction seen was within 20% of the maximum achievable when controls were applied at any of the six plants.

10.2.2 Reductions Calculated on the Basis of Optimum
 Cost Allocation

As a second method of assessing how to reduce impact from SO₂ emissions, the Ministry applied a fixed amount of dollars for SO₂ removal in various ways, and then calculated the amount of deposition reduction seen at various receptors. This is basically Approach 2 discussed previously in Section 10.1. Conclusions from this analysis were that:

- ° Control expenditures (in terms of amount of SO₂ removed per dollar spent) were most effective for Lambton and Nanticoke, next for Lakeview, and then for the smaller emitters.

- ° When a fixed amount of dollars was spent at either Lambton or Nanticoke, the amount of emissions reductions produced a benefit of deposition reduction for all areas which was equal to or larger than the benefit seen by applying dollars in other ways. This occurred because the amount of emissions removed was always great enough to offset, or more than offset, the different impacts of deposition per ton of emissions which existed for each plant. In other words, even if control at Lambton or Nanticoke was not as "effective" on a per unit emission basis

as at other plants, the costs of control were so low at the two plants, that when the same amount of money was applied, the net environmental benefit was greater overall.

- ° The conclusion from this analysis was that if Ontario Hydro spent a set amount of money from its budget, which in turn meant that it was raising its electrical rates by a certain percentage, it was "most effective" to institute controls at Lambton and Nanticoke. The phrase "most effective" applies to cost and environmental aspects of the problem.

10.2.3 Reductions Calculated from Known Deposition Target Values

Approach I in Section 10.1 states that if the D_i are known, one can solve for values of E_j . After applying some constraints (such as specifying the number of sources and receptor areas, eliminating some values of E_j) the solution may become harder to find, or non-existent.

For the Hydro application, the Ministry did not explore this approach, because, at the time the abatement analysis was done (in the fall of 1980) "target values" of deposition were not known. Recent U.S./Canada Memorandum of Intent Phase II Reports¹ have established target values, and this approach is being explored for other abatement strategies.

10.2.4 Summary of Modelling Use in Ontario Hydro
 Abatement

The preceding sections show how the model of long range transport was used as a guideline in the development of the Ontario Hydro control regulation. See Appendix 1, Chapter 8). The Ministry scientists and policy analysts realized that the model was not "perfect". However, for the extent of emissions reductions contemplated - about 25 to 50 per cent - the model was judged to give valuable information in the following areas:

- ° describing relative benefits of various scenarios for a set of ecologically sensitive areas spread out over thousands of kilometers;
- ° describing how benefits change as a result of applying one emission reduction scenario in various ways, to various sources separated by many hundreds of kilometers;
- ° describing how benefits change when a fixed amount of money is applied to emission reductions in a variety of ways;
- ° relating the differences in environmental benefit to differences in cost; and

- ° presenting a broad picture of what level of deposition reduction to expect (i.e., between 2 and 5 percent, or between 20 and 40 per cent?)

The model was one tool in the analysis, but it was certainly not the only tool. Other factors, such as the speed with which the controls could be instituted; the type of control best suited to the facility (e.g., scrubbers, low sulphur coal, or not using the plant and switching generation elsewhere); the overall cost of the program; and the size of the system's reductions (e.g., 25% or 50%) were all part of the analysis.

The emissions program for Hydro was framed by a Regulation of the Crown which was announced in January, 1981. Under this regulation, Ontario Hydro will reduce SO₂ emissions by 43 per cent by 1990. Emissions of NO will also be reduced.² The measures which will be employed to achieve this reduction involve: retrofitting 500 megawatt scrubbers, probably at the Lambton station, using low sulphur coal at the other two large plants (Lakeview and Nanticoke); operating the larger fossil-fueled plants on a LEDS (Least Emissions Dispatching System) philosophy; constructing more nuclear plants; and importing more hydroelectric power from Manitoba and Quebec.

10.3 Application of the Model to INCO SO₂ Control

The INCO SO₂ reduction was promulgated in the summer of 1980. It ordered INCO to reduce smelter stack emissions of SO₂ from a maximum of 3600 tons per day to 2500 tones per day immediately, and in 1983 emissions must be no more than 1950 tons per day. (See Appendix 1, Chapter 8).

The Ministry's long range transport model was employed while the Regulation was being developed to gain an idea of how much of a deposition reduction one could expect in various sensitive North American areas. The details of INCO's impact are given elsewhere, (See Appendix 2, Remarks by Dr. G. Van Volkenburgh), and what is worthwhile noting is that the model is useful as a guideline, even when one large source is being assessed for control: The results of modelling are very useful, because they demonstrate the geographical extent of impact, and the expected amount of reduction in deposition which occurs in various regions. What the modelling revealed to the Ministry was that, even though INCO was one of the Western world's largest sources of SO₂, significant reductions in its emissions would not solve the "acid rain" problem in other locations.

Put another way, modelling of one source's impact when its emissions are altered and other sources in an aggregation (which includes several states and provinces) do not change, is instructive because the model, as a guideline or one tool, demonstrates how the impact of altering emissions from one source affects the solution to a regional problem. The model is as applicable in calculating SO₂ concentrations as it is calculating other important pollutant impacts which result from SO₂ emissions - that is, sulphates, acidic aerosols and particulates, dry deposition of acidic species, and "acid rain" itself.

10.4 Summary

The "case samples" discussed above illustrate compelling reasons why the use of long range transport models should begin to be integrated into the regulatory framework of E.P.A.'s interstate pollution impact considerations. Such modelling offers a way to systematically consider:

- ° the amount of impacts
- ° the extent of impacts
- ° how impacts alter when various sources of SO₂ in an aggregation are assessed for control.

- ° how impacts are altered when different cost constraints are applied to various sources in an aggregation.

The fact that the models are not yet "perfect" does not prevent them from being employed as one tool among many - or as a guideline. The key is to use the modelling results with a clear awareness of the limitations of those results.

References - Chapter 10

1. United States - Canada Memorandum of Intent on Transboundary Air Pollution. Working Group I. United States - Canada Memorandum of Intent on Transboundary Air Pollution Impact Assessment Working Group I Phase II Interim Working Paper October 1981. Submitted to Canada/United States Co-ordinating Committee by C.I. Harris, U.S. Co-Chairman and G.E. Bangay, Canadian Co-Chairman on October 8, 1981.
2. Ontario Hydro. Acid Gas Control Program Status Report as of May 31, 1981. This Quarterly Report provides information on the progress of Ontario Hydro's acid gas control program developed to comply with Provincial acid gas emission requirements of Ontario Regulation 73/81 made under the Environmental Protection Act 1971.

11. FINANCIAL IMPLICATIONS OF THE
COSTS OF SO₂ AND NO_x REDUCTIONS ON
ELECTRIC POWER UTILITIES IN
THE UNITED STATES

11.1 Introduction

The costs of additional SO_x and NO_x emission controls are expected to be large and many authorities are understandably concerned about the possible effects of these costs on the particular emission source sectors, upon those who are employed by firms in these sectors and upon groups and sectors which purchase the products and services of firms being subjected to controls. Indeed, there is a reluctance on the part of governments to impose stringent control objectives, as well as a strong resistance from firms to comply with abatement programs, because of the real and imagined economic disruptions that may result from these costs. An economic assessment of abatement programs or scenarios is needed, therefore, to verify or refute these concerns as well as to help determine a socially desirable level of emission control.

The purpose of this Chapter is to examine some of the financial implications of sulphur dioxide (SO₂) abatement efforts on the electric power industry in the Eastern U.S.* Three types of implications are of importance. First, the costs of achieving specific emission objectives may impose financial burdens directly on electric power companies.

*Fossil-fuelled electric power plants with a capacity of 200 megawatts (MW) or greater in ten Eastern U.S. States are the focus of this Section. These 10 States include Ohio, Indiana, Illinois, Michigan, West Virginia, Missouri, New York, and Tennessee.

Second, these costs and expenditures will have indirect economic effects on fuel suppliers and on the regions in which power plants are located. Finally, the effects of these costs on inflation, on employment and on investment in the national economy is of concern. Relevant information on these economic implications will be assembled and discussed.

While the magnitude of the costs of control may be large, a number of factors will act to mitigate the impacts of these costs on the power companies and on the various sectors, groups, firms and individuals that will ultimately bear them. Evidence is presented to show that significant reductions in SO₂ emissions from U.S. power plants can be achieved without causing undue economic disruptions to the electric power industry and to the communities and regions in which they operate.

11.2 Economic Feasibility and "Affordability"

Actions and facilities to reduce SO₂ emissions will require the expenditure of money and effort. These abatement activities will also generate two types of benefits: private and public.

Private benefits of pollution abatement are the savings in materials, reductions in waste or the extra revenues gained from selling recovered by-products. Private benefits are generally captured by the party that bears the costs.

The use of low sulphur coal can have private benefits in terms of lower costs of boiler operation. Flue Gas Desulphurization can generate private benefits if a saleable by-product is recovered.

Public benefits are the reduction or avoidance of pollution damages that result from the abatement program. Public benefits are generally enjoyed equally by people who are otherwise unconnected with the polluter. The polluter cannot exclude anyone from receiving public benefits. Hence it can collect no revenues for providing clean air or water. Reductions in damages to plants, to buildings or to fish populations as well as reduced public health risk are examples of public benefits.

From a public perspective, an abatement program is economically feasible when the sum of the private and public benefits is greater than, or equal to, the total costs of the program. However, where the costs of abatement to be borne by the polluter substantially exceed private benefits, the financial and economic disruptions that may be imposed on the polluter are a subject of concern. The government is faced with the dilemma of determining how much private production (i.e. abatement costs and possible closure of some facilities) should be given up to achieve public environmental benefits.

The question of affordability by the polluter is, therefore, separate from the question of economic

feasibility from the public view point. The appropriate criterion on which to base decisions about abatement programs is the degree to which the program achieves public and private benefits, not whether the polluter can or cannot "afford" abatement. Financial assistance programs can be initiated to offset the economic disruptions caused by abatement costs if necessary.

The detrimental environmental impact of SO₂ emissions are documented elsewhere in this submission. In this Chapter, it is further argued that electric power utilities or the regions in which they are located are not likely to be economically damaged by SO₂ abatement efforts.

11.3 The Significance of U.S. Power Plants to the LRTAP Problem

Power plants are the single largest contributors of SO₂ emissions in the U.S. About 27 million tonnes of SO₂ were emitted by all sources in the U.S. during 1978 along with 23.3 million metric tonnes of NO_x. These data are summarized in Table 11.1. Of these emissions, 17.6 million tonnes, or 65% of total SO₂ emissions, were generated by electric utilities. These figures are presented in Table 11.2. The next largest SO₂ sources are industrial boilers and industrial processes which account for 12% and 15% of total emissions respectively. Emissions data for all sources and for electric utilities only in these States are

listed in Table 11.3. According to these data, approximately 52 percent of the total U.S. SO₂ emissions and 31 percent of total U.S. NO_x emissions originate from these ten States. Electric power utilities, in turn, account for 82% of the total SO₂ emissions from these ten States and about 50% of the NO_x emissions.

These 10 States, along with Texas, are the top 11 generators of SO₂ (MOI, Work Group 3B, p.92). These same 10 States, along with Florida, Louisiana and Texas, also generate nearly all of the NO_x produced in the U.S.

The individual power plants in these States with rated capacities above 200 MW are listed in Appendix 15. The locations and the owners of the plants are noted along with the percent load factor and the estimated SO₂ emissions during 1979. The State Implementation Plan (SIP) emission objectives for each plant in terms of pounds of SO₂ per million BTU's of fuel burned are listed for each plant, as well as the percent sulphur in coal that is required to meet the 1979 SIP objectives. Those plants that currently have Flue Gas Desulphurization (FGD) systems installed are also noted.

A total of 154 plants are listed. All but two of these plants burn coal as the primary fuel, although some burn other fuels as well. Coal combustion is, however, considered to be the primary source of SO₂ for purposes of

this discussion. In total, these plants generate about 104 million tonnes of SO₂ per year or about 59% of the total SO₂ emissions generated by the electric power utility sector in the entire U.S.

11.4 Pollution Control Technologies

Five basic methods can be applied to reduce residualemissions from fossil-fuelled power plants:

- (a) reduction in the production of electricity;
- (b) use of naturally low sulphur fuels;
- (c) removal of sulphur from fuels before combustion;
- (d) reaction with an absorbant during combustion;
- (e) removal of sulphur after combustion.

With respect to the general methods (b) through (e), a total of 16 specific abatement technologies are identified in the MOI Work Group 3B Interim Report (MOI, February 1981) ranging from coal cleaning to various Flue Gas Desulphurization (FGD) techniques and systems. These technologies are summarized in Table 11.4.

Of all the methods listed, the use of low sulphur coal (below 1.0% sulphur content) is the method most preferred by

power companies to achieve SO₂ emission objectives for several reasons. First, the installation of abatement equipment and systems requires the allocation of scarce capital funds for which the companies have other uses which are, from their own standpoint, more desirable. Second, power companies can more easily obtain the approval of their State Utility Regulatory Commissions to pass higher fuel costs of low sulphur coal through to consumers than cost increases resulting from capital expenditures. Finally, power generation is a relatively simple thermo-mechanical process. The addition of FGD systems (scrubbers) involves a complex chemical operation which power plant personnel apparently have neither the experience nor inclination to undertake.

Power plants and utility companies throughout North America also employ such technologies as coal washing and cleaning, and, as indicated in Appendix 15, a few have installed FGD Systems.

Reductions in NO_x emissions can be achieved by altering boiler design and operation. The application of technologies to abate SO₂ also affects the choice of methods to control particulate material. Retrofitting emission controls is especially expensive because of the extensive changes in other systems that are sometimes required.

There is a great deal of debate about the technical reliability and performance of FGD systems and technologies. However, enough operating experience has been accumulated in the U.S. and Europe to show that certain of these systems do work.

Various combinations of methods and technologies can be used at each power plant to achieve a wide range of SO₂ emission reductions at varying levels of costs. A combination that will be examined in this paper is the use of generally cheaper "high" sulphur coal (above 2% sulphur content) in conjunction with FGD systems. Scrubbers operate more cost effectively with higher concentrations of sulphur dioxide.

11.5 Estimating the Costs of SO₂ Emission Controls

SO₂ emission objectives differ substantially among power plants. These objectives are based on the National Ambient Air Quality Standards specified in the Clean Air Act and which are explicitly intended to protect human health. Two types of emission objectives are relevant to electric power plants. The first type of source emission objective is that found in the State Implementation Plan (SIP). Emission objectives for SO₂, NO_x and particulate matter are established in State Implementation Plans. These objectives are individually calculated for each power plant to achieve the Primary National Ambient Air Quality Standards for the

particular area in which the generating station is located. These objectives apply to all power plants, old and new, and often differ substantially from plant to plant.

The second type of emission objective relevant to power plants are the New Source Performance Standards (NSPS). These are applicable to new generating stations or to new units in existing plants which have a capacity greater than 73 MW and which have a heat input of greater than 250 million Btu's.

Estimates have been made by the U.S. EPA of the costs of achieving SIP and NSPS objectives by power utilities and other source sectors. Electric power utilities throughout the U.S. are reported to have spent, during 1979, a total of \$3.5 billion (1979 dollars) in capital expenditures. A total of \$6.3 billion in operation and maintenance costs were estimated to have been spent to meet SIP or NSPS objectives (Council for Environmental Quality, 1980, p.397). Additional expenditures for water pollution brings the total capital expenditures to \$4.0 billion. These estimates, which were prepared by the U.S. EPA, are summarized in Table 11.5. By contrast, electric power utilities invested about \$27 billion per year in capital expenditures during 1979 and 1980 (U.S. Statistical Abstract, Section 18, 1980). Thus, 15 percent of the capital expenditures undertaken by power companies in recent years has been for air and water pollution control.

As indicated in Table 11.5, electric utilities are expected to have spent a total of \$121.2 billion (in 1979 dollars) on capital facilities and operating costs to achieve air pollution control by 1988. Another \$11.4 billion are expected to have been spent on water pollution control over the same period. The sum of these figures amounts to 18% of the \$735.0 billion projected to have been spent on environmental protection activities in all sectors during the 10-year period between 1979-1988.

Such estimates indicate the magnitudes of possible costs but are of limited use in policy evaluations and decision-making. They do not reflect the variety of technological and management options that can be applied in the power plants nor do they indicate the varying levels of environmental or public benefits that are achieved at different levels of emission control.

There is no meaningful "single cost" value to achieve future abatement. Rather, systems models are required to estimate the range of future abatement costs under different assumptions and circumstances. Examples of these types of models are the Coal and Electric Utilities Model (CEUM) developed by ICF Inc. for the U.S. EPA, the Department of Energy and Argonne National Laboratories and the Utility Simulation Model (USM) developed by Teknekron Research, Inc. (Van Horn et al., April 1981). These simulation models permit the development of abatement scenarios with explicit

assumptions about the many variables that are associated with power plants. These models can be used to calculate the costs of emission controls and, in the case of the ICF model, the consequences of different scenarios in terms of emissions, capital and operation and maintenance costs, cost per ton of SO₂ removed and shifts in coal demand and production.

Sector-specific models (CEUM and USM) have not yet been used to fully evaluate all possible abatement scenarios. Those scenarios that have been tested indicate that the magnitudes of the capital costs are in the order of \$3 to \$7 billion per year, amounts which are not appreciably greater than the current levels of capital expenditures. The results of the models also indicate that, where the use of low sulphur coal is a principle means of effecting SO₂ emission reductions, sales from coal mines in the mid-western States (Ohio, Illinois, etc.) would decline substantially and coal costs would be increased as well.

The application of econometric models is required to determine the aggregate effect of abatement costs on the economy as a whole. Every two years, the U.S. EPA commissions an assessment of macroeconomic effects of expenditures mandated by federal Regulations and legislation. For the period 1970 to 1987, a simulation of the performance of the U.S. economy with the costs of federal requirements (e.g. expenditures by the electric

power utility industry along with other sectors) was compared with the economic performance that would have occurred without these expenditures (Data Resources, Inc., July 17, 1981). The un-priced public benefits of pollution control are not included in these estimates. Based on these analyses, it was concluded that price increases would only be about 0.5% lower with abatement costs than without. The average annual rate of economic growth (in real GNP) is reduced by only 0.1 of a percentage point by the presence of the pollution control costs. Employment is stimulated throughout the 1970-1987 period by the abatement costs, as is business investment. The overall economic effect of a sustained effort to achieve pollution abatement is neutral for the economy as a whole.

11.6 A Comparison of Two Approaches to Achieve 1979
 State Implementation Plan SO₂ Objectives
 at Power Plants in 7 States

Power companies prefer to achieve SO₂ emission control objectives by burning low sulphur coal. As noted in Table 11.4, a potentially greater degree of SO₂ emission reduction can be achieved by scrubbing flue gases produced by burning high sulphur coal. The cost implications of these two control approaches were compared by means of the following procedure:

- (1) For 143 power plants in 9 midwestern States, the actual cost, in mills per KWH, of coal used by each plant in 1979 was regressed against the percent sulphur in the coal*. An expected inverse relationship was found between the two variables for the data sets from seven of the States. That is, the higher the sulphur content, the lower the cost of coal. Data from Pennsylvania and Tennessee exhibited a direct relationship and were omitted from further calculations. Data sets used in the regression analyses are presented in columns 2 and 3 of the Tables in Appendix 16.
- (2) The estimated coefficients for each State equation were then used to estimate the cost of coal (in mills per KWH) at any given level of sulphur content.
- (3) The percent sulphur content in coal that would be required in order to meet the 1979 S.I.P. objective was then calculated for each plant. These figures are shown in Column 4 of Tables 16-1 to 16-7 of Appendix 16.
- * New York was not included in this analysis.
- (4) Using these percent sulphur figures, the estimated cost of the coal that would be required to achieve the S.I.P. objectives was calculated with the relevant

regression equations. This cost is presented in mills per KWH, and is listed, for each plant, as Column 5 in Tables 16-1 to 16-7.

- (5) For comparative purposes, the cost of installing and operating FGD systems is estimated to be 6 mills per KWH (T.A. Burnett, et al., 1980). This factor was subtracted from the cost estimates in column 5.
- (6) The differences in estimates listed in column 6 of Tables 16-1 through 16-7 indicate the maximum cost of coal that could be paid so that the total cost of higher sulphur coal plus scrubbing would equal the cost of low-sulphur coal that would be required to achieve the SIP objectives.
- (7) Applying the estimated equations, the per cent sulphur in coal that could be purchased at the price (in mills per KWH) indicated in column 6 was calculated and listed in column 7 in the Tables 16-1 through 16-7 in Appendix 16.

The results of this analysis indicate that, for a substantial number of power plants, it would be cheaper to install scrubbers and buy lower cost, "high sulphur" coal than to purchase "low sulphur" coal. Moreover, a greater degree of SO₂ emission reduction would be achieved since FGD systems can potentially effect more SO₂ reduction than is

possible with low sulphur coal. In some plants, scrubber costs obviously overwhelm coal costs. However, these results indicate that more careful analyses of the application of Flue Gas Desulphurization at many U.S. power plants is warranted. Based on this assessment of the economic consequences, scrubbing may well be a more cost-effective means of achieving SO₂ reductions than the use of low sulphur coal.

11.7 Impacts of SO₂ and NO_x Abatement Costs on the
Electric Power Industry and on Regional Economies

Whatever abatement methods are employed, the magnitude of the financial costs of SO₂ and NO_x control at U.S. power plants will certainly not be trivial. However, the financial burdens imposed by these abatement requirements on power companies and associated groups will be mitigated by several factors. First, there is a wide range of technical methods and options that can be employed to achieve reduced NO_x and SO₂ levels at widely varying costs by different power companies. Computer models can be employed to determine which plants cause the most damage and abatement effort can be allocated accordingly. Second, declining growth in electricity demand can increase the scope for offsetting fossil-fuel production capacity with nuclear and hydro capacity by some power companies.

The cost burdens of new capital facilities is shared to a substantial extent between tax-paying utility companies and governments in the form of taxes foregone. Costs can be

further mitigated by scheduling the abatement program over a number of years. Finally, there is potential for large savings from technological innovation once firms direct their efforts and talents toward abatement rather than litigation.

While information about cost burdens on power companies is pertinent, the most appropriate comparisons for public policy development and decision-making is whether the total (public plus private) benefits of pollution control investments are greater than, or equal to, the total costs. Society can "afford" any level of environmental or pollution control quality for which the benefits are perceived to be commensurate with the costs. These costs may include higher electricity rates or even temporary unemployment. In actions and in public opinion polls, the North American public has clearly shown its willingness to pay for higher environmental quality.

Evidence indicates that the current and the potential economic burdens on U.S. electric power utilities for pollution control are substantial but not unmanageable. Moreover, analytical tools are available that permit environmental agencies to determine cost-effective strategies and to identify those regions and firms that are potentially most seriously affected. With this information, strategies and policies can be developed which will minimize total costs, which can balance benefits and costs and which can help to apportion these costs in an efficient and equitable manner.

TABLE 11.1

TOTAL U.S. AIR POLLUTION EMISSIONS ESTIMATES, 1970-78

Year	Total Suspended Particulates	Sulphur Dioxide	Nitrogen Dioxide	Volatile Organics	Carbon Monoxide
(million metric tons per year)*					
1970	23.2	29.8	19.9	28.3	102.6
1971	22.0	28.2	20.6	27.8	103.1
1972	21.0	29.3	21.6	28.3	104.4
1974	17.9	28.5	21.8	27.1	99.6
1975	14.6	26.2	20.9	25.3	97.2
1976	14.1	27.4	23.4	27.0	102.9
1977	13.6	27.2	23.4	27.1	102.4
1978	12.5	27.0	23.3	27.8	102.1
Percentage change, 1970-78	-46.1	-94.4	+17.1	-1.8	-0.5

* 1 million metric tonnes = approximately 1.1 million short tons.

Source: U.S. Environmental Protection Agency, National Air Pollution Emission Estimates, 1970-1978, EPA 450/4-80-002 (Washington, D.C., 1980), p.2.

TABLE 11.2
SOURCES OF SO₂ AND NO_x
EMISSIONS IN THE U.S., 1978

Category	SO ₂		NO _x	
	(10 ⁶ tonnes/yr.)	(% of total)	(10 ⁶ tonnes/yr.)	(% of total)
Electric Power Utilities	17.6	(65%)	7.2	(31%)
Industrial Boilers	3.2	(12%)	4.9	(21%)
Industrial Processes	4.1	(15%)	0.8	(3.5%)
Transportation	0.8	(3%)	9.4	(40%)
Residential/Commercial	1.3	(5%)	0.8	(3.5%)
Solid Waste Disposal	0.0	(0%)	0.1	(0.5%)
Miscellaneous	0.0	(0%)	0.1	(0.5%)
Total	27.0	(100%)	23.3	(100%)

Source: U.S. Canada, Memorandum of Intent on Transboundary Air Pollution, Interim Report - February 1981 - Work Group 3B - Engineering Costs and Emissions, p.91.

TABLE 11.3

SO₂ AND NO_x EMISSIONS, TOTAL AND ELECTRIC POWER UTILITIES

1977 and 1978

State	Total State Emissions		Total Electric Power Utility Emissions		Electric Power Utilities as a % of State Emission Total	
	1978		1977		NO _x	
	SO ₂ (10 ³ tons)	NO _x	SO ₂ (10 ³ tons)	NO _x	SO ₂	NO _x
Illinois	1,747.2	1,129.9	1,369	602	78.4	53.3
Indiana	1,848.2	600.6	1,493	462	80.8	76.9
Kentucky	1,330.0	563.0	1,093	346	82.2	61.5
Michigan	1,117.8	843.1	745	230	66.7	27.3
Missouri	1,307.7	563.0	1,265	315	96.7	56.0
New York	1,041.1	908.9	508	262	48.8	28.8
Ohio	3,115.3	1,277.1	2,688	529	86.3	41.4
Pennsylvania	1,900.0	1,120.7	1,476	391	77.7	34.9
Tennessee	1,162.8	595.9	1,091	229	93.8	38.6
West Virginia	1,049.5	462.4	1,048	263	99.86	56.9
TOTAL	15,619.6	8,061.1	12,777	3,929	81.8	48.7
U.S. National Total (10 ³ tons)	29,760	25,680	19,797	7,191.9	82.6	37.0
U.S. National Total (10 ³ tonnes)	27,000	23,300	17,959.7	6,524.4	82.6	37.0

SOURCE:

- (unless otherwise footnoted) U.S.-Canada Memorandum of Intent on Transboundary Air Pollution, Interim Report, Feb. 1981, Working Group 3B. pp. 92-94.
- 1) Ontario, A Submission to the U.S. Environmental Protection Agency Opposing Relaxation of SO₂ Emission Limits in State Implementation Plans and Urging Enforcement, Mar. 1981, p. 12. (1979 emissions).
 - 2) "U.S. Power Plants Survey for 1979", power plants generating in excess of 200 MW. Information obtained from MOE, Air Resources Branch. (1979 emissions).

TABLE 11.4
CONTROL TECHNOLOGIES FOR SO² REDUCTION

SYSTEM	PERFORMANCE	COST	APPLICABILITY	UNCERTAINTY	WASTE DISPOSAL	PROBLEMS
Wet F.G.D. Limestone Lime	Acceptable Availability (90% or)	Limestone: \$120-\$200/kW Lime: \$200/kW	All fuels	Cost is a function of size, sulphur content, location, redundancy or equip- ment, whether ash removal included.	Preferably oxidized to gypsum, other- wise settling problems in ponds and landfill, unless chemically fixed.	Waste disposal because of volumes. Utilities skeptical of costs and reli- ability.
Dual Alkali	Acceptable Availability	Actual \$80-\$242/kW	All fuels	Limited experience.	As above.	As above.
Wellman Lord	Limited experi- ence so far.	Actual \$259/kW	All fuels	Uncertain market for by-products.	Potential water pollution problem.	High Cost.
Dry Scrubber	Limited experi- ence so far.	\$120-\$140/kW including e.s.p., but rising	Low sulphur fuels	Performance data sparse.	Lime systems have minimal problems, whereas soda-based units have poten- tial water pollu- tion problems.	Waste disposal involves large volumes. Opera- tional difficul- ties with varia- tions in coal characteristics.
Low-Sulphur Fuel	Coal Cost depen- dent very much on distance & charges. Oil Adds \$5 per barrel	Coal	Coal	Incremental costs, availability of supplies.	No problem.	Boiler derating, effects on precipitator, transportation, logistics.
Physical Coal Cleaning	Effective up to 25% sulphur removal	Can add up to \$15 per ton	Used for high pyritic sulphur and coals.	Coal variability and expansion of existing facilities.	Water pollution and solid waste disposal.	Energy losses, maintaining quality control.

SOURCE: U.S.-Canada Memorandum of Intent on Transboundary Air Pollution, Interim Report, Feb. 1981, Working Group 3B, p.4.

ESTIMATED TOTAL U.S. POLLUTION ABATEMENT EXPENDITURES, 1979-88

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	1979			1988			Cumulative (1979-88)		
	Operation and main-tenance	Annual capital costs	Total annual costs	Operation and main-tenance	Annual capital costs*	Total annual costs	Operation and main-tenance	Annual capital costs	Total annual costs
(billions of 1979 dollars)									
Air pollution									
Public	1.7	.4	2.1	2.8	.7	3.5	22.5	5.3	27.8
Private									
Mobile	3.2	4.9	8.1	3.7	11.0	14.7	32.1	83.7	115.8
Industrial	2.5	2.9	5.4	3.9	5.1	9.0	32.5	41.5	74.0
Electric utilities	6.3	3.5	9.8	8.5	6.5	15.0	71.1	50.1	121.2
Subtotal	13.7	11.7	25.4	18.9	23.3	42.2	158.2	180.6	338.8
Water pollution									
Public	3.7	8.2	11.9	5.4	14.2	19.6	45.4	99.7	145.1
Private									
Industrial	4.4	3.2	7.6	6.4	5.1	11.5	52.4	41.4	93.5
Electric utilities	.4	.5	.9	.4	1.1	1.5	3.6	7.8	11.4
Subtotal	8.5	11.9	20.4	12.2	20.4	32.6	101.4	148.6	250.0
Solid waste									
Public	1.7	.3	2.0	2.5	.6	3.1	21.8	5.3	27.1
Private	4.5	.7	5.2	7.5	1.6	9.1	61.3	12.5	73.8
Subtotal	6.2	1.0	7.2	10.0	2.2	12.2	83.1	17.8	100.9
Toxic substances	.1	.2	.3	.5	.6	1.1	3.6	4.6	8.2
Drinking water	.3	.4	.7	.5	.8	1.3	5.3	5.2	10.5
Noise	.05	.1	.1	.6	1.0	1.6	2.6	4.3	6.9
Pesticides	.1	.05	.1	.1	.05	.1	1.6	.1	1.7
Land reclamation	.4	1.3	1.7	.4	1.4	1.8	4.5	13.5	16.0
Total	29.3	26.6	55.9	43.2	48.7	92.9	360.3	374.7	735.0

* Interest and depreciation.

SOURCE: U.S. Council on Environmental Quality. Environmental Quality - The Eleventh Annual Report of the Council on Environmental Quality. Washington D.C., U.S. Government, Printing Office, Dec., 1980
p. 397.

References - Chapter 11

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12. EFFECTS OF ACIDIC DEPOSITION ON ONTARIO'S AQUATIC SYSTEMS

Sensitive aquatic systems which receive acid, both directly and indirectly from precipitation, can suffer chemical and biological damages. This chapter discusses the nature and magnitude of these effects in Ontario as evidenced through research on the province's aquatic ecosystems.

12.1 General Nature of the Lake and River Acidification Process

Acids falling on the earth's surface may be neutralized by chemical reaction with basic materials in the soil and water. Areas underlain by rock containing large amounts of basic material (such as limestone) can neutralize the acids for indefinite periods of time with only minor changes in the chemical composition of the runoff. If, however, the soils and bedrock have little capacity to neutralize the acid (for example, the sparingly soluble rocks of the Precambrian Shield) the acid loading can exceed the neutralizing capacity and runoff water will be acidic with consequential biological damage in streams and lakes.

The alkalinity of lake and river water is a chemical measure of its capacity to neutralize acid and is commonly referred to as the buffering capacity. The greater the alkalinity, the greater the capacity to neutralize acid. Lakes in areas of calcareous (limestone) soils have high alkalinities and pH values generally above 7.0. By contrast, unpolluted lakes located in hard rock geological conditions (such as the Precambrian Shield area of Ontario) have low alkalinities and pH values generally in the range of 6.0 to 7.0. While these lakes are on the acidic side of pH 7.0, they still have healthy aquatic life.

Lakes with low alkalinity are regarded as sensitive to the effects of acid rain since they have a low capacity to maintain (or buffer) the pH at acceptable values when excessive acid is added from the atmosphere.

When excessive acid loadings from the atmosphere are applied to sensitive areas, the pH of the runoff may be reduced to values well below 6.0 for a few weeks time during spring snow melt or for a few hours or days during heavy summer and autumn rains. Lakes which suffer short term pH depression or have their summer pH values slightly reduced are called "acid stressed" lakes.

Over time, the acid loading can virtually exhaust the neutralizing (or buffering) capacity of the soils in

sensitive areas and the runoff can become nearly as acidic as the rainfall itself. When the alkalinity of streams and lakes falls to zero (pH 4.5-5.0), the waterbody is called "acidified". At these pH levels, fish populations are severely stressed and will eventually be lost.

Therefore, the ultimate result of deposition of acids in sensitive areas is acidification of the surface water with loss of fish populations and concomitant damage to other aquatic life forms. These effects have been well established for lakes and rivers in Scandinavia and the Adirondack Mountains affected by acid deposition.³²

12.2 Research Approach to Aquatic Effects

Under the current patterns of acidic precipitation, virtually all of the lakes located in Precambrian rock in Ontario are being subjected to acid loadings above "background" levels. Precipitation with pH near 5.6, the value expected for equilibrium with atmospheric carbon dioxide, contains about 2.5 ueq/l of acid (hydrogen ion). The observed concentrations in bulk deposition are about 11 ueq/l at Kenora* (4 times the "background" level²⁹) and up to 70-90 ueq/l in the important recrea-

* Located in Northwest Ontario, Northeast of the Ontario - Minnesota Border. Area Code 2, Map 2.1.

tional areas of Muskoka-Haliburton** (28-36 times the "background" level²⁷). For several years, environmental studies have been undertaken in these areas designed to determine the resulting water quality and biological responses in the lakes and streams. Data presented in this section are derived from these studies.

The lakes, rivers and watersheds themselves are the ultimate "collectors" of atmospheric pollution deposited by wet and dry mechanisms. One research approach considers lakes and watersheds in this manner, and has led to establishing "calibrated watersheds", which are combinations of watersheds, streams and lakes under intensive measurement. This approach is an established research tool and was used in the development of strategies for the management of eutrophication of lakes by phosphorous control. The calibrated watershed studies are prime sources of information on acid rain effects.

Hydrologic weirs (Figure 6.1) are set up on the streams entering and leaving a particular study lake. The flows of water and dissolved substances are accurately measured and combined with the best possible measures of atmospheric inputs and of water loss by evaporation to calculate "substance budgets".

** Located in South - Central Ontario. Area Code 1, Map 2.1.

The difference between the inputs measured by the budgets and the inputs measured from wet deposition can give estimates of dry deposition.

The calibrated watersheds are subjected to detailed chemical and biological sampling and thus serve to quantify the chemical and biological effects of pollutant deposition. Relationships established by detailed studies can be extrapolated to large numbers of lakes for which less complete data are available.

Calibrated watersheds have been established at many locations (Figure 6.2) such as Kenora, Sault Ste. Marie and Dorset in Ontario, Laurentide Park in Quebec, Kejimikujik Park in Nova Scotia, Hubbard Brook in New Hampshire, Sagamore Lake in New York and Coweeta in North Carolina. For each study site, a data base of atmospheric loadings and resulting aquatic and terrestrial effects is being compiled. Conclusions regarding effects are drawn from comparisons between areas and from long term observations in each area. Extensive results for Ontario are available from the Kenora and Dorset study locations.

12.3 Observed Effects on Water Quality

12.3.1 Surface Water Quality

Many lakes near Sudbury, Ontario have been acidified by atmospheric deposition of acids.^{5, 11} The problem was regarded as "local" due to emissions of sulphur dioxide from copper and nickel smelters. It was addressed by reducing emissions and by commissioning the world's highest smoke stack in 1972 to utilize the dilution capacity of the atmosphere for the largest single sources in the area. Ground level sulphur dioxide concentrations due to the local sources had caused discomfort to people and damage to vegetation and both problems have essentially been eliminated by the control programs.

The Sudbury situation is well known because of its size, particularly the INCO Ltd. smelter, but it is not unique. During the 1970's hundreds of other plants and industries were built in the United States and Canada which utilized high stacks to disperse wastes. Emission reductions were seldom applied; dilution by the atmosphere was expected to solve the "problem".

The overall result is that today in North America there are hundreds of atmospheric sources of sulphur and nitrogen oxides from the burning of fossil fuels and non-ferrous smelting operations, all depending on

atmospheric dilution to resolve part of the waste problem.

In recent years it has become well understood that the acid rain problem in Ontario is not confined to the Sudbury area¹³ and that the Sudbury sources were only a small part of the total emissions to the atmosphere leading to the acid deposition in Ontario.

Historical evidence of acidification in other areas of Ontario is difficult to obtain because of the limited amount of baseline data. However, one well documented case is that of Clear Lake in Muskoka-Haliburton. The summer alkalinity value of Clear Lake was 33 ueq/l in 1967 and only 2-15 ueq/l in 1977 indicating a net loss of buffering capacity.¹³ In other words, the lake is acid-stressed. This lake is only unique in that accurate historical data were available. There is no reason to doubt that many other sensitive Ontario lakes have already shared the same fate and that many thousands more will follow in due course if no abatement action is taken.

To ascertain the geographical breadth of the problem, lake alkalinity values were measured on some 1,527 lakes in various areas of the Precambrian Shield (Table 6.1). The number of lakes sampled in each area to date is small in comparison to the total lakes in these

areas, but based on this data, it is becoming clear that a very high percentage of the lakes in the entire Precambrian Shield fall in the extremely or moderately sensitive categories.

The lakes in the extreme sensitivity category are currently acid stressed and are likely to be acidified by long range transport if current acid loadings continue. Loss of buffering capacity is cumulative, its rate and timing dependent on the rate of deposition. Once lost, there is nothing to prevent the lake from quickly acidifying. This supposition is supported by the long term observation of lake acidification in Scandinavia⁸ and the Adirondacks.²⁵

On a short-term or episode basis, detrimental water quality effects are being observed now. In both areas of Ontario intensively studied to date, acids (hydrogen ions) from atmospheric deposition are neutralized during most of the year. Retention (neutralization) of hydrogen ions has been measured at 88% and 98% on an annual basis at Kenora and Dorset respectively.²⁰ However, the hydrogen ions stored in the snowpack enter streams and lakes in the spring thaw and most of the total annual acid input occurs during the spring melt. The large volume of water, coupled with less chance for interaction with the frozen soils results in "shock" loadings of acid to streams and the surface waters of lakes.

Jeffries et al²² compared pH values of a series of small streams and lake outlets measured before and during spring melt at Dorset (Table 6.2). The lowest pH values observed in the lake outlets (4.8-5.0) are within the range capable of causing damage to aquatic life, particularly fish. As much as 76.6% of the measured yearly discharge of acid from the watersheds occurred in April. Figure 6.3 shows a typical hydrograph for one of these streams, emphasizing the high spring water flow, high acid discharge and low pH values. Scheider et al²⁸ further observed that the pH of streams was depressed for periods of a few hours during times of heavy runoff after summer storm events (Figure 6.4). Heavy autumn rains also cause depressed pH in runoff for a few days at a time. In one particular year of study, as much as 25.8% of the total annual hydrogen ion runoff from small watersheds occurred in October.

There are 32 calibrated watersheds under study in the Dorset area and some have results for a period of five years. The results described here are typical of the full set of observations and it can be concluded that atmospheric acid loadings are causing periodic water quality changes. The study lakes all have low alkalinities but are representative of thousands of lakes in the Precambrian area.

In addition to direct effects on surface water pH, acidic precipitation has the potential of increasing the leaching rate of material from the watershed. Aluminum is a major constituent of the bedrock material in the Precambrian area and it tends to be dissolved by acidic runoff. Scheider et al²⁸ reported an average total aluminum concentration of 49 ug/l for the study lakes at Dorset. Concentrations in streams are typically up to 200-300 ug/l with some measurements exceeding 500 ug/l, particularly in the spring runoff (Scheider, pers. comm.).

Laboratory experiments have shown that survival of brook trout was reduced to less than 50% after 14 days at aluminum concentrations of 420 and 480 ug/l at pH values of 5.2 and 4.4 respectively.¹⁴

It appears that the pH and aluminum concentrations being observed in the Dorset study lakes during spring snow melt fall within the ranges which laboratory experiments have shown to be lethal to fish.

12.3.2 Ground Water Quality

Hultberg and Wenblad²¹ have identified a number of shallow wells in Sweden which have become acidic as a result of acidic precipitation infiltrating soils with very low neutralizing capacity. The acid water has

caused serious corrosion of plumbing and in some cases entire systems of copper pipes have had to be replaced after 10 to 15 years of use. The acidic wells are characterized by rock outcrops allowing surface runoff to move to sandy subsoil with minimal contact with surface soils. There is little opportunity for the neutralizing capacity of the surface soils to be utilized in neutralizing the runoff.

Many wells in the Precambrian area of North America servicing seasonal cottages and permanent homes are located in similar geological conditions so the potential for acidification of ground water exists. The first field surveys were carried out in 1980 in the Muskoka-Haliburton area of Ontario.³⁰ A total of 89 ground water samples were analyzed for pH. Ground water was sampled from shallow springs and at various depths in wells obtaining water from both bedrock and overburden formations.

Eleven of the 89 samples had pH values less than 6.0, with the lowest value being 5.2. Subsequent resampling (summer, fall) of five of the low pH values resulted in only one sample still having a pH of less than 6.0.

12.4 Observed Effects on Aquatic Biota

12.4.1 Fish

Although water quality changes are a concern in their own right, it is the biological responses to acidification which are of uppermost importance. Damage to fish populations is a major concern as it represents a loss to the sport fishing industry and serious disruption of the biological food chain since so many birds and mammals depend on fish for food. Complete loss of fish tends to be regarded as the definition of a 'dead' lake.

The reported effects of acidification to fish are many and varied. Harvey¹⁶ reported fish kills in Plastic Lake in Haliburton during the spring melt when the surface water pH of the lake was 5.5 and the inlet streams had a pH of 3.8. Fish caging experiments in the spring of 1981 (H. Harvey, per.-comm.) confirmed the toxic nature of the water, particularly of the inlet stream (pH 4.0-4.1) where 100% of the caged fish died in two days. Shortly after the caging experiment SCUBA divers observed dead fish in the lake as well.

Loss of fish populations has been documented for several lakes in Ontario concurrent with lake acidification.¹⁹ The mechanism of extinction is usually failure of recruitment of new age classes into the

population, as observed at Patten Lake (Figure 6.5).²⁶ Another phenomenon in acid-stressed lakes is loss of older fish from the population. Figure 6.6 illustrates the age distribution of white suckers in George Lake near Sudbury during a 13 year period while the lake was becoming acidic.^{3, 6, 18} Figures 6.7 and 6.8 show age distributions of white sucker in Crosson, Red Chalk and Harp Lakes in Muskoka-Haliburton.¹⁷ The acid-stressed Crosson Lake (pH 5.4-6.4) has an age distribution similar to George Lake showing the shift to younger age classes compared to the neutral Red Chalk Lake (pH 5.5-7.2) and Harp Lake (pH 5.8-7.0).

White suckers are an important "test species" since they are not subject to fishing pressure and therefore, any changes in population are due to environmental effects.

These observations provide strong evidence that the fisheries are beginning to suffer under the present acid loading conditions. It is reasonable to assume that similar changes are taking place in the many thousands of lakes with similar alkalinities which are likely experiencing similar water quality effects.

12.4.2 Mercury in Fish

Since elemental, metallic mercury can exist in the gas phase at ordinary air temperatures it has become ubiquitous in the environment. Large quantities of mercury pass between the earth and the atmosphere by natural cycling processes which have been going on for millions of years. Therefore, the mere presence of mercury in any compartment of the environment does not necessarily imply any human influence.

Man's propensity to utilize the atmosphere for the disposal of wastes influences the natural mercury cycle in two ways. Firstly, man's activities directly increase the total amount of mercury entering the atmosphere. Secondly, the amount of mercury in fish and other aquatic organisms is increased due to the acidification of surface waters by acid deposition.

Regarding the first influence, it has been estimated that on a global scale human activities have increased the mercury emissions to the atmosphere by 27%²³ but it is not known how this increase influences the global mercury cycle. Within eastern North America, however, the situation is quite different. Man-made mercury discharges to the atmosphere from the U.S. states bordering on the Great Lakes are 170% of the natural atmospheric loading.²³ States farther south which may

still influence the Precambrian area by long range transport have similar man-made atmospheric discharges.

Coal contains on average of about 60 ng/g of mercury¹² and up to 97% may be emitted from stacks upon combustion.⁷ The mean residence time in the atmosphere has been estimated to be 11 days.²³ Therefore, there is plenty of time for long range transport prior to deposition. These points are of particular concern regarding any policy to increase the use of coal as an energy source.

If all other factors were equal, one could expect such large increases in atmospheric emissions to increase the deposition rate and hence, the concentrations of mercury in living organisms. However, increased deposition has not yet been fully substantiated as atmospheric studies on mercury have only been carried out in a preliminary way to date.

Regarding the second factor influencing the natural mercury cycle, that is, acidification of surface waters, it has already been demonstrated as cause for concern. Acidification of lakes takes place over a time period measured in years or even decades. During this time there will still be fish in the water although the average pH of the water will be slowly declining. It has been shown that the lower pH conditions tend to cause increases in the mercury concentrations in fish.^{15, 9, 2}

The result is, that over a long period of time, lakes and rivers subjected to acid stress will still have some fish but the mercury concentrations in those fish will increase. Birds and animals which eat fish as a major part of their diet will ingest quantities of mercury which may well threaten their health and survival.

Suns³¹ has been sampling young-of-the-year and yearling fish for contaminant studies. This approach reduces some of the variables since the fish are uniform with respect to age and diet. The data (Figure 6.9) demonstrates increased mercury concentrations in fish from lakes with lower pH in the Haliburton area of Ontario. It was further shown that for lakes with similar pH, the mercury was higher in fish from lakes with a higher ratio of drainage area/lake volume. This result implies that the quantity of mercury from either direct atmospheric deposition or watershed leaching is influencing the mercury concentrations in fish. The surveys have not been carried out long enough to establish any trends with time.

In 1980, the survey was extended to include adult bass which are an important component of the sport fishery. Bass from six of the nine lakes studied had average mercury concentrations above the Canadian guideline for unlimited human consumption of 500 ng/g. In one lake, the U.S. guideline of 1000 ng/g was exceeded.

The fisheries within Ontario are the basic resource for a sport fishing industry valued at hundreds of millions of dollars per year. While in the long-term, acidification of lakes poses a threat to the industry, in the short-term, mercury in fish could lead to further restriction on human consumption of the fish with consequential economic loss to the industry.

12.4.3 Other Biological Effects

In the Muskoka-Haliburton area, densities of several species of amphibians decrease with increasing acidity of their habitat. Acidic lakes and streams support a smaller breeding population of spring peepers (Hyla crucifer) than more neutral habitats. Deciduous woodland ponds are the typical breeding habitats for Ambystoma salamanders. However, such ponds have been observed in Muskoka-Haliburton to be very acidic with pH's as low as 4.3. These acidic ponds are now seldom used as breeding sites and thus represent a loss of habitat for this species. The hatching success of any eggs laid in these habitats is low.¹⁰

Although relatively little work has been done to date on the effects of acidification on aquatic macro-invertebrates in Ontario, numerous aquatic insects are known to be affected by acidification and their distribution has been related to the pH of lakes and rivers

(reviewed by Harvey et al.²⁰). From these studies it appears that mayflies and stoneflies are usually sparsely distributed in acidic waters. Molluscs (snails and clams) and moulting crustaceans are very sensitive to low pH waters.

The acidification of lakes in Ontario is accompanied by changes in the occurrence and abundance of zooplankton and reductions in the diversity and biomass of zooplankton communities.²⁰ Both these tiny animal forms and the aquatic macroinvertebrates (insects, clams, snails, etc.) form important links in the aquatic food chain capped by the top predators, fish.

The decline of macrophyte plant species and the concurrent invasion of *Sphagnum* reported in acidified lakes in Scandinavia and the Adirondacks (reviewed by Harvey et al 1981²⁰) has not yet been recorded in Ontario lakes. *Sphagnum* moss coverage of the nearshore areas of lakes creates a habitat unsuitable for use as fish spawning and feeding grounds.

The algae growing in acid stressed and acidic lakes undergo changes in species abundance which may be detrimental to the recreational use of the lakes and pose a threat to the habitat of some aquatic organisms. For example, lakes with reduced pH support a proliferation of algae attached to the bottom (benthic filamentous

algae). These algae can coat gravel fish spawning beds making successful spawning impossible. Significant growths of these algae have been observed in Muskoka-Haliburton lakes such as Plastic, Chub and Leonard.

Another observed change, detrimental to recreational activities, is the appearance of an alga called Chrysochromulina breviturrita Nich. which is characterized by a severe "rotten cabbage" or "garbage dump" odour which has caused lakes to be unsuitable for swimming. The alga has reached problem concentrations in four lakes in Ontario and one in New Hampshire in the past three years. Crosson Lake has experienced the problem. Dickie Lake had an extreme problem in 1979 and it has had cottagers there for over 20 years with no previous observations of the odour.²⁴ The odour is so bad that residents would likely have remembered had it ever occurred before.

The alga has now been identified at various population sizes in over 40 lakes in Ontario, most of which have low pH.²⁴

Although little information has been collected on the role of microorganisms in acid stressed systems, studies have shown that microbial decomposition of organic matter is reduced at low pH (reviewed by Harvey et al 1981) ²⁰. It is believed that such disruptions

will affect the nutrient cycling and hence other trophic levels in acidified surface waters.

12.5 Summary of Aquatic Effects

The current acid loadings to parts of the Precambrian rock areas of Ontario, and in particular the important recreational areas of Muskoka and Haliburton, are causing some lakes and rivers to have low pH values for a few weeks during spring melt and for several hours or days during heavy summer and autumn rains. These lakes are regarded as acid-stressed. Aluminum levels in some study streams are in the range of values known to be lethal to fish from laboratory studies.

The alkalinity of Clear Lake in Haliburton has declined by 60% over the last 10 years. This lake is unique only in that long-term measurements are available. Sixty to ninety per cent of the lakes surveyed in this area of Ontario are classed as extremely or moderately sensitive to acidic inputs.

Intensive studies on the biological effects of observed water quality changes are being carried out in a small number of lakes. Fish kills have been observed in one lake. Complete loss of fish populations concomitant with lake acidification are known for several lakes, the mechanism being recruitment failure. The loss of older

fish in the population is observed in acid-stressed Crosson Lake.

Mercury concentrations are elevated in fish from lakes with pH values below about 6.0. There is reason to suspect that increased man-made atmospheric emissions of mercury from coal burning, coupled with acidification of precipitation and surface waters, will lead to higher mercury concentrations in fish and to more lakes being affected.

Any loss or modification of the quality of sport fish is a major concern to the sport fishing industry valued at hundreds of millions of dollars per year in Ontario.

The potential for other biological effects has also been shown and in many cases damage has been documented by field observations. Observed effects on biota in acidified systems include a decline in the breeding population of certain amphibians, reduced numbers of zooplankton and benthic macroinvertebrates, changes in algal communities, the occurrence of a foul smelling alga that restricts recreational use of the lake and decreased microbial decomposition rates with potential effects in lake trophic status.

The acid stressed lakes under study are showing many instances of biological damage. It is highly likely that similar damage is occurring in the thousands of similarly acid-stressed lakes.

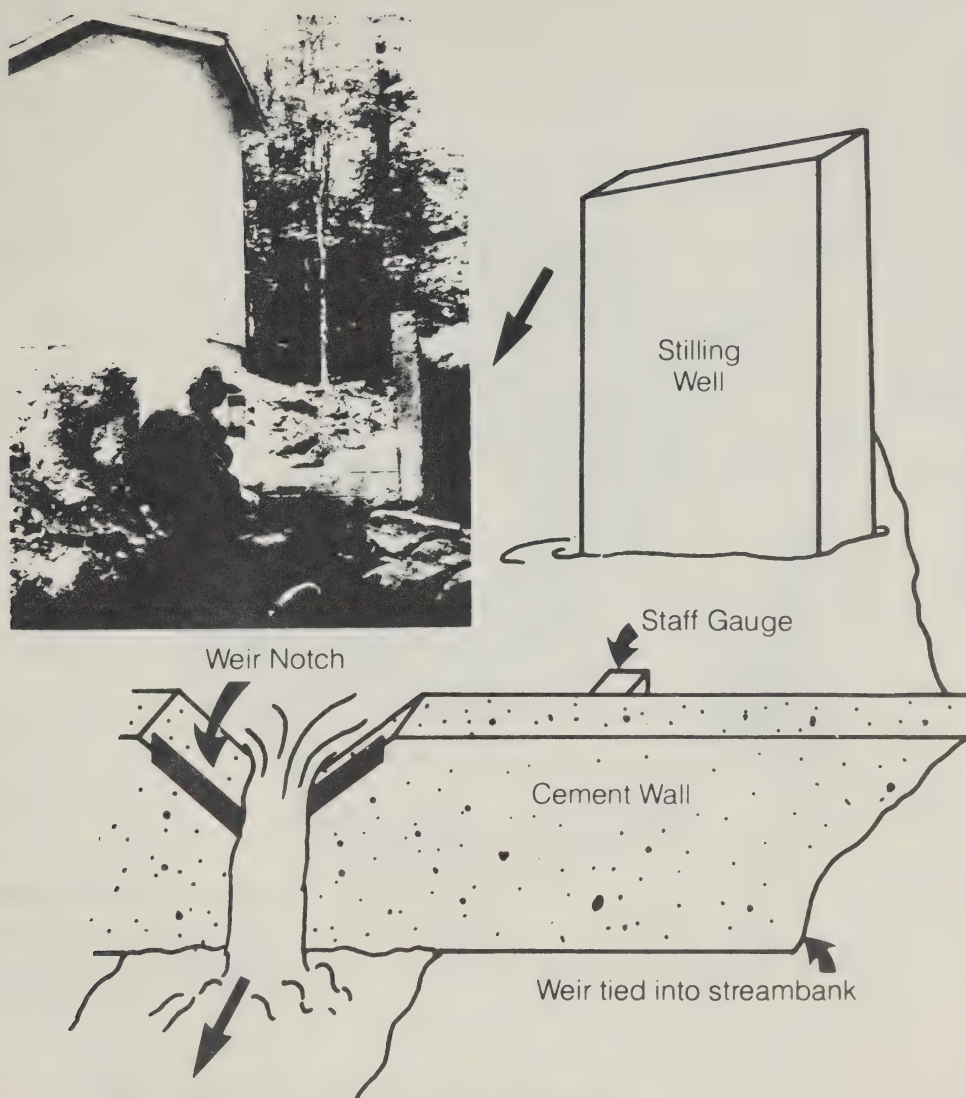


Figure 12.1 Actual and schematic examples of a weir designed to accurately record the flow of water in streams. Water samples are frequently collected for chemical analysis and concentrations and total amounts of chemical constituents passing through the weir are calculated.



Figure 12.2 Regions of North America containing lakes that are sensitive to acidification by acid precipitation, based on bedrock geology, showing where calibrated watershed studies on sensitive areas are in progress.

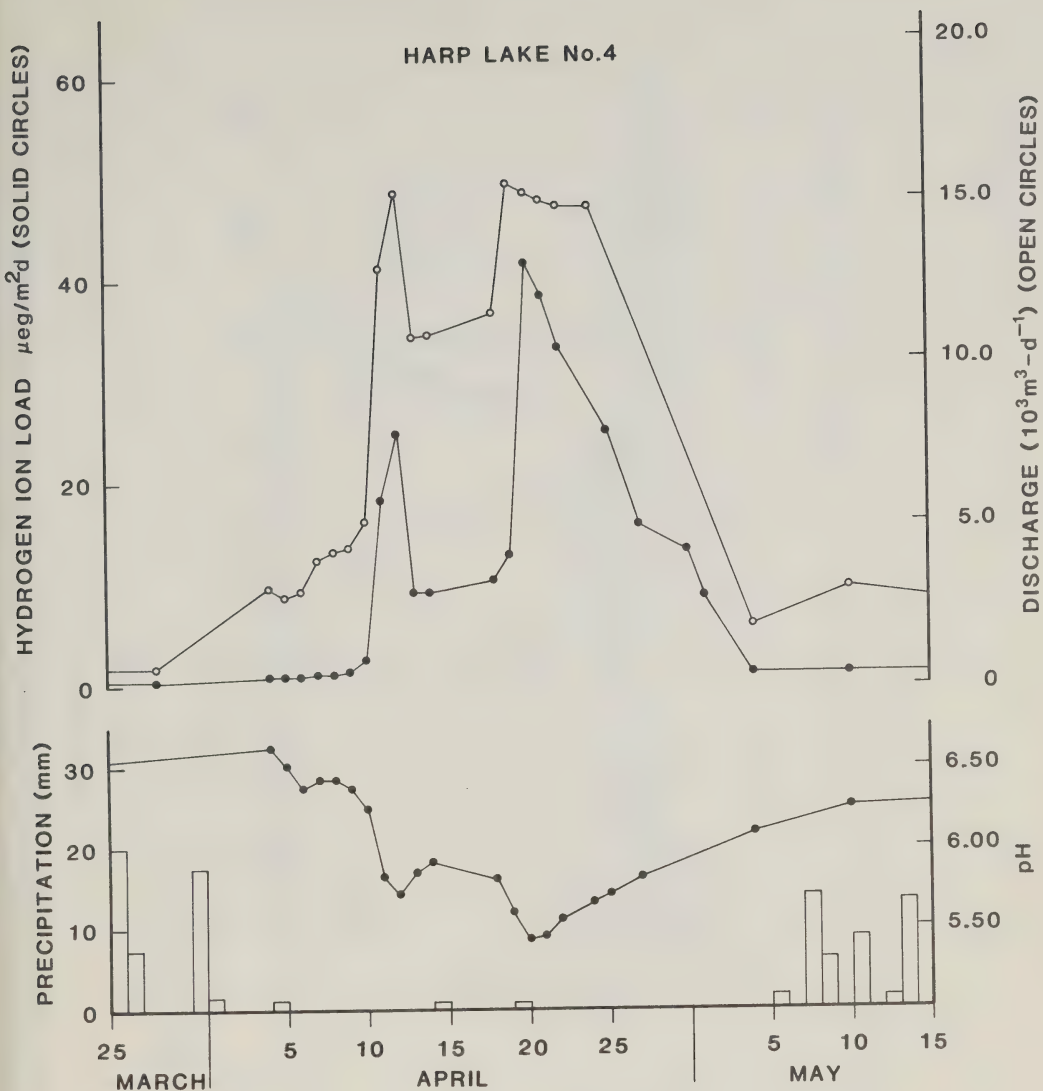


Figure 12.3 "Spring pH Depression" of a Stream

Graph illustrating "spring pH depression" in one of the six inflowing streams to Harp Lake, a study lake in Muskoka. As the spring runoff increases the amount of water, the acidic melted snow causes the stream pH to drop, producing severe chemical "shock" effects on aquatic life.

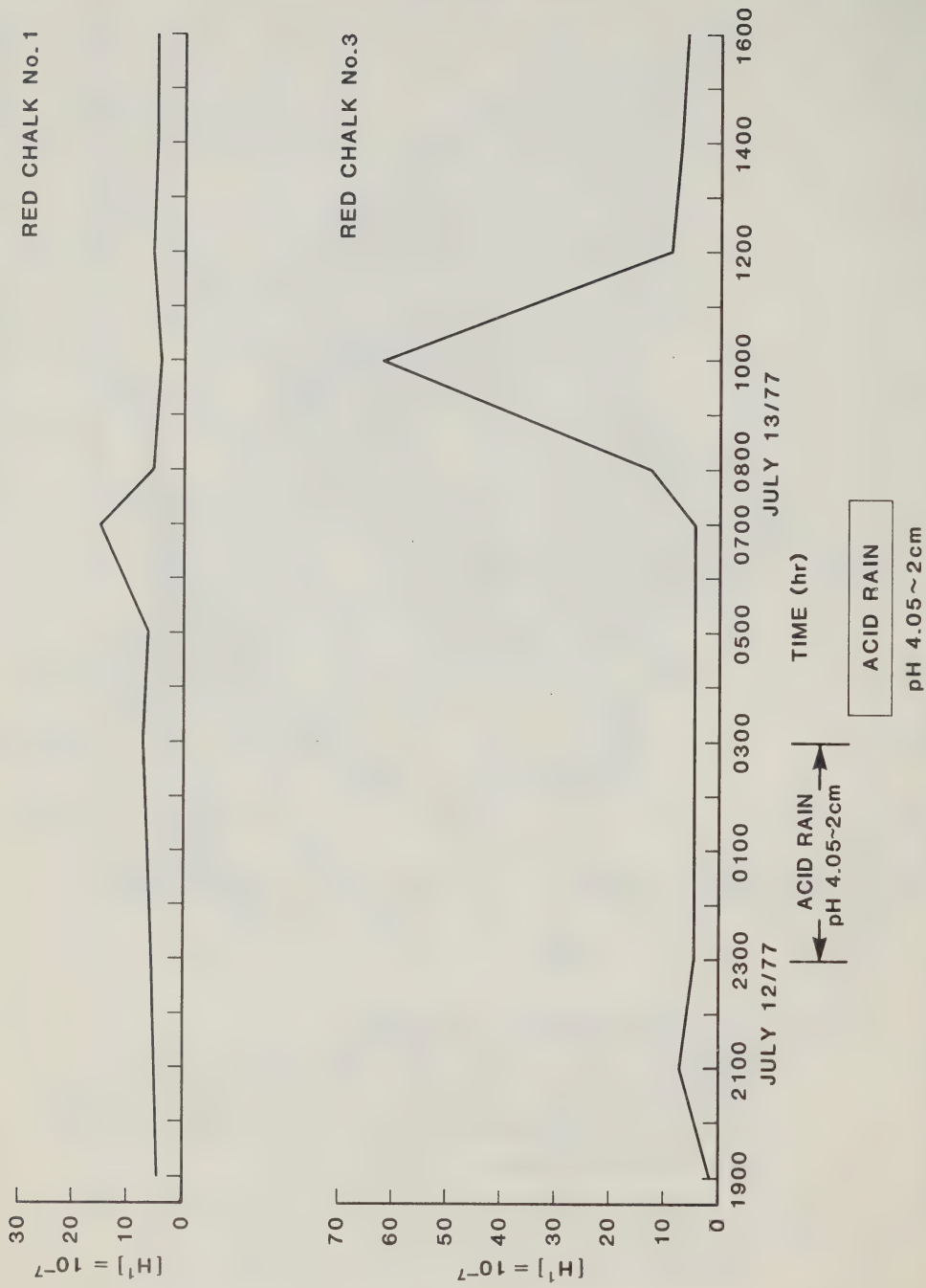


Figure 12.4 Hydrogen ion content of streams draining Red Chalk Lake watersheds No. 3 and No. 1 (Dorset, Ontario) showing effects of a 2cm rainfall (pH 4.06) between 11:00p.m. July 12, 1977 and 3:00a.m. July 13, 1977.

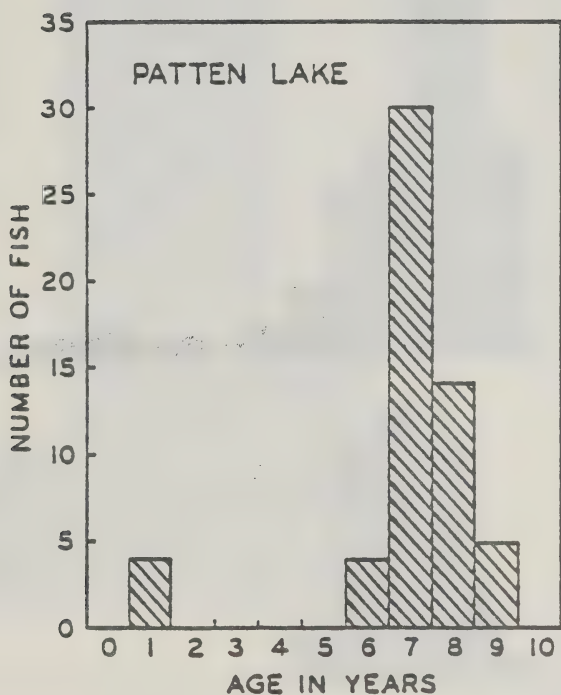


Figure 12.5 Age composition of yellow perch (*Perca flavescens*) captured in Patten Lake, Ontario, pH 4.1 (26)

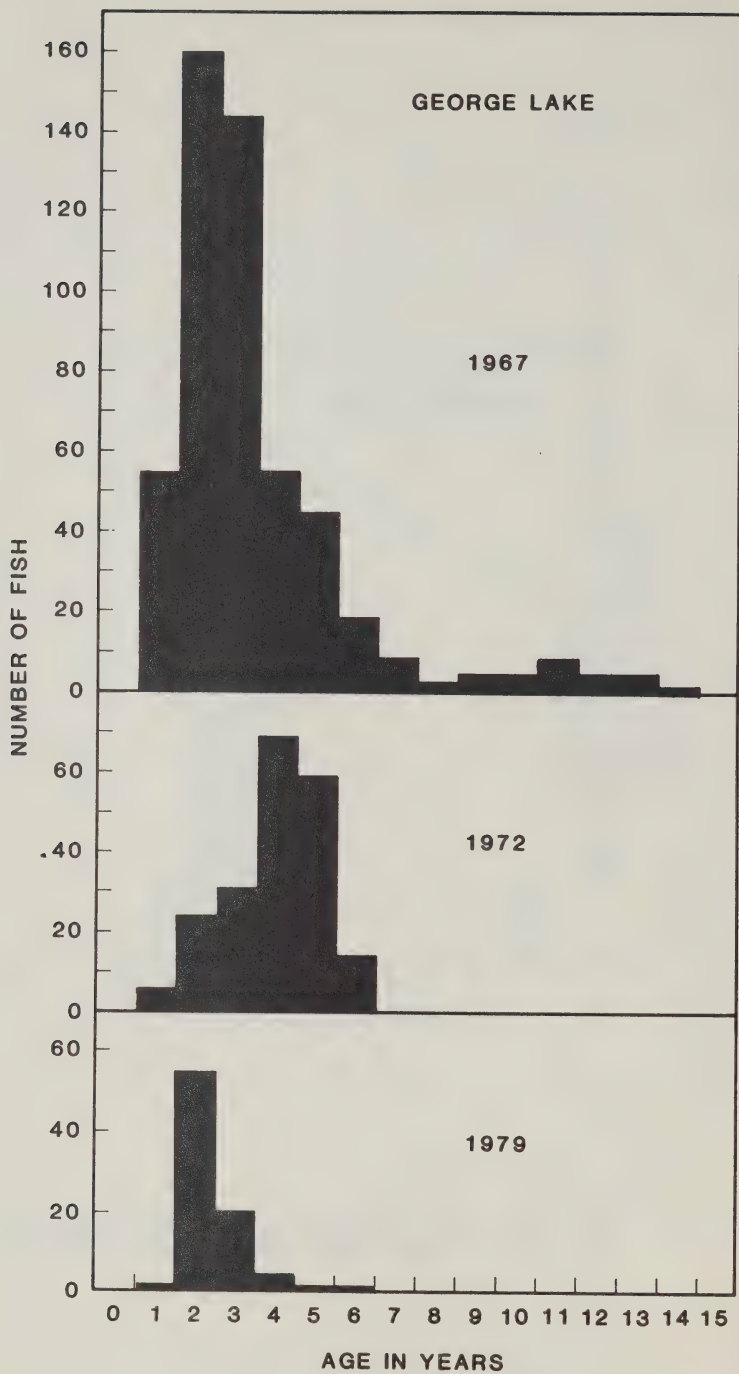


Figure 12.6 Changes in the age composition of the White Sucker in George Lake, Ontario (3, 6, 18).

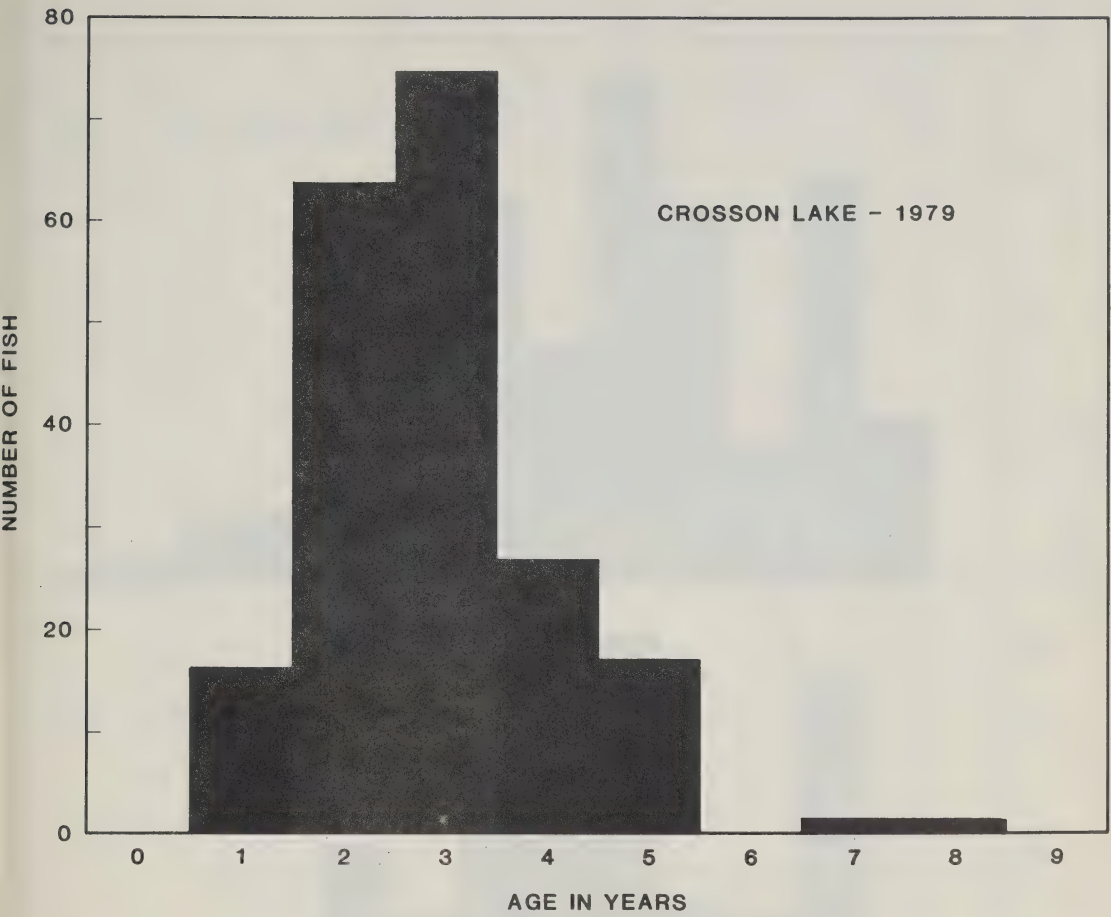


Figure 12.7 Age composition of the White Sucker in Crosson Lake (17).

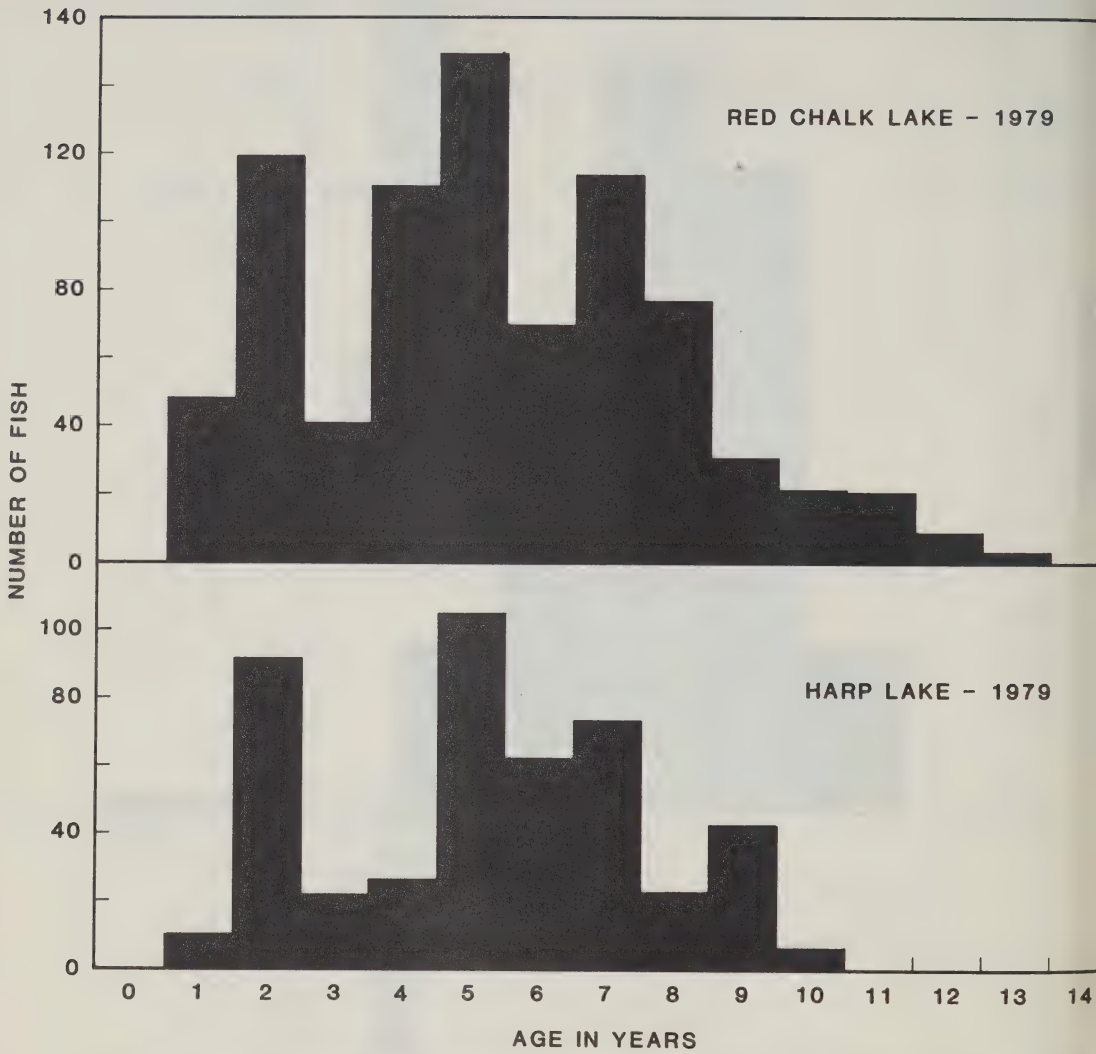
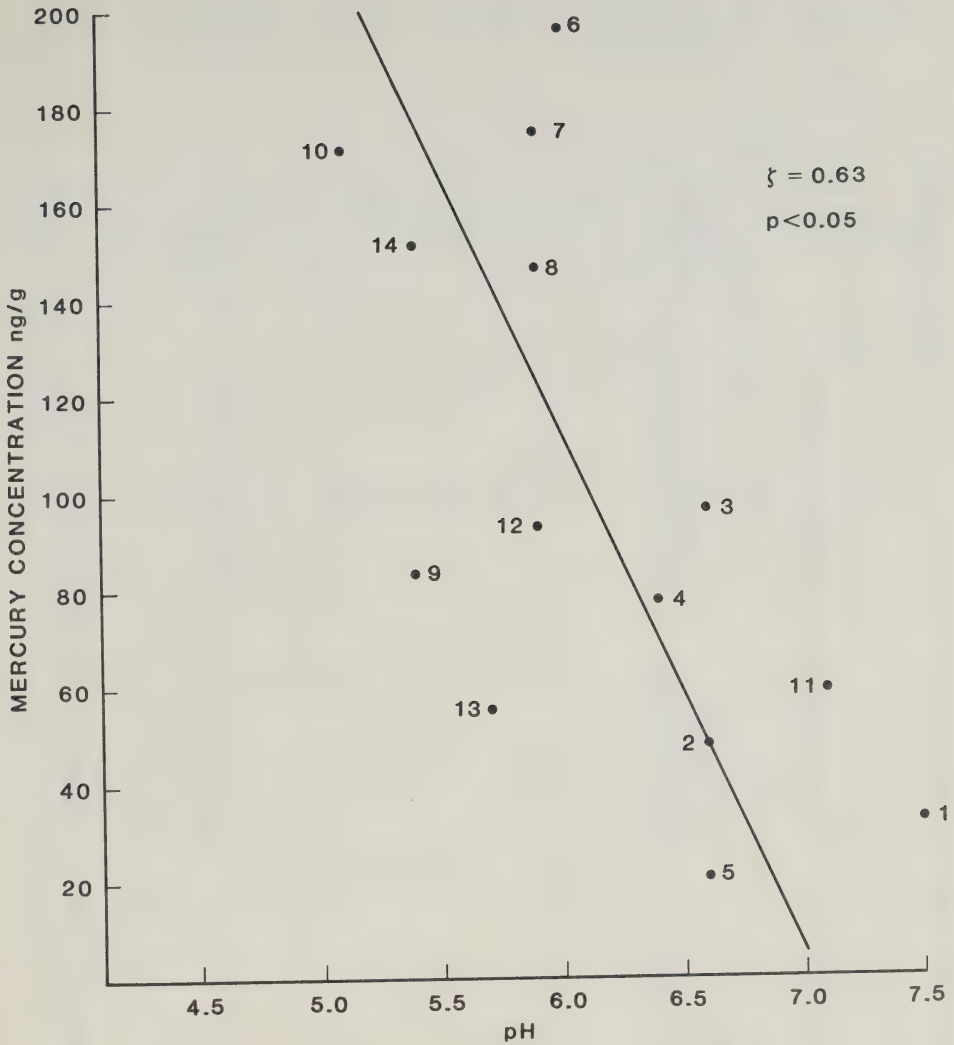


Figure 12.8 Age composition of White Sucker for Harp and Red Chalk Lake, 1979 (17).



1978 DATA

LAKE #, NAME	TWP.	LAKE #, NAME	TWP.
1 DUCK LAKE	MINDEN	8 DICKIE LAKE	McLEAN
2 LITTLE CLEAR LAKE	SINCLAIR	9 LEONARD LAKE	MONCK
3 HARP LAKE	SINCLAIR	10 HENEY LAKE	McLEAN
4 BIGWIND LAKE	OAKLEY	11 CRANBERRY LAKE	GUILFORD
5 NELSON LAKE	BOWELL	12 HEALEY LAKE	McCAULEY
6 CHUB LAKE	RIDOUT	13 CLEAR LAKE	STANHOPE
7 CROSSON LAKE	OAKLEY	14 FAWN LAKE	McCAULEY

Figure 12.9 Mercury concentrations in yearling yellow perch and epilimnetic pH relationships (31).

TABLE 12.1 SUMMARY OF THE PERCENTAGE OF LAKES IN EACH ALKALINITY CLASS BY COUNTY OR DISTRICT

Percentage of Total No. of Lakes in each Alkalinity Class					
County or District	Acidified (≤ 0 $\mu\text{eq/l}$)	Extreme Sensitivity (> 0 to 39.9 $\mu\text{eq/l}$)	Moderate Sensitivity (40 to 199 $\mu\text{eq/l}$)	Low Sensitivity (200 to 499 $\mu\text{eq/l}$)	Not Sensitive (≥ 500 $\mu\text{eq/l}$)
					Total No. of Lakes Surveyed In County/ District
Algoma District	5	11	30	28	163
Bruce Co.				26	7
Cochrane Dist.		7		100	27
Durham Co.				82	1
Frontenac Co.				100	64
Grey Co.				94	3
Haliburton Co.		24		100	112
Hastings Co.			39	15	63
Huron Co.			21	11	1
Kenora Dist.			14	25	88
Lanark Co.				61	15
Leeds Co.				100	24
Lennox & Addington Co.			36	52	25
Manitoulin Dist.	52	29	3	12	31
Middlesex Co.				3	1
Muskoka Dist.	1	30	61	2	115

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Nipissing Dist.		9	75	13	3	75
Northumber- land Co.					100	1
Ontario Co.					100	5
Parry Sound Dist.	5	20	64	10	1	107
Peel Co.					100	1
Peterborough Co.		4	16	6	74	49
Prince Edward Co.					100	3
Rainy River Dist.		3	64	19	14	99
Renfrew Co.			8	32	60	50
Simcoe Co.					100	7
Stormont Co.					100	1
Sudbury Dist.	24	29	23	12	12	210
Thunder Bay Dist.	1	2	25	27	45	136
Timiskaming Dist.	13		7	27	53	30
Victoria Co.					100	11
York Co.					100	2
						1,527

TABLE 12.2

pH OF STREAMS IN MUSKOKA-HALIBURTON, ONTARIO, CANADA:
STREAM pH IS GIVEN PRIOR TO SPRING RUNOFF (MID-MARCH 1978)
AND AT MAXIMUM RUNOFF (MID-APRIL 1978)

Annual Average Alkalinity data from Scheider (Pers. Comm)

Waterhshed	Annual Average Alkalinity µeq/l	Stream Number	pH	
			Mid-March	Mid-April
Harp Lake	96	3	6.1	5.1
		3A	6.0	5.6
		5	5.9	4.8
		6	6.2	5.3
		6A	5.4	5.0
		Outflow	6.3	5.0
Dickie Lake	55	5	4.6	4.3
		6	4.6	4.4
		11	4.9	4.1
		Outflow	5.6	4.9
Chub Lake	61	1	5.8	5.1
		2	5.2	4.7
		Outflow	5.5	4.8
Red Chalk Lake	92	1	6.1	5.6
		2	4.5	4.3
		3	6.0	5.5
		4	6.2	5.5
		Outflow	6.1	5.9

Partial Table From: Jeffries et al., 1979

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13. TRANSBOUNDARY AIR POLLUTION

DIRECT EFFECTS ON VEGETATION

13.1 Introduction

A number of air pollutants generated by various sources can cross international boundaries and also transgress state and provincial borders. The main pollutants in this air mass which are or have the potential to be phytotoxic are sulphur dioxide (SO_2), ozone (O_3), and acidic precipitation. Sulphur dioxide which is emitted by a large number of sources including power plants and smelters is usually deposited near the sources or transformed chemically in the atmosphere to other sulphur compounds. Thus SO_2 concentrations in remote areas at a distance from the source are normally reduced and not likely to cause acute adverse vegetation effects. However by oxidation to sulphates and hydrolysis to sulphuric acid, SO_2 contributes to the formation of the secondary pollutant acidic precipitation. Similarly ozone is a secondary pollutant, not being emitted directly by any source, but formed in the atmosphere in the presence of sunlight after chemical transformations of nitrogen dioxide and reactive hydrocarbons. These two secondary pollutants, acidic precipitation components and ozone, can be considered to be long range transported pollutants since they occur in high

concentrations in ambient air at distances of hundreds of kilometers from the sources of the precursor pollutants. The direct effects on vegetation are well known and documented for sulphur dioxide and ozone based on observations made both in the field and in laboratory experiments. However, only experimental evidence is available for acidic precipitation, with no direct effects having been conclusively documented in the field for vegetation exposed to ambient precipitation.

This section on the direct effects on vegetation of transboundary air pollutants will discuss in order sulphur dioxide, ozone, and acidic precipitation.

13.2 Sulphur Dioxide - Direct Effects on Vegetation

Sulphur is an essential element for plants. Normally sulphur is taken up by plants from soil in the sulphate form and assimilated into various compounds usually after being chemically reduced. Sulphur dioxide absorbed from the air has been shown to rapidly undergo oxidation inside plant tissues. It is apparent that sulphur in its various forms is necessary in the intermediary metabolism of plants.

Background levels of SO_2 in the atmosphere are 4 ug m^{-3} * or less (Georgii 1970) and there is no evidence that

* Conversion factor used to convert mass/volume units to volume/volume units of concentration (at 25°C and 760 mm hg) multiply by 3.82×10^{-4} ; or $1 \text{ ppm} = 2600 \text{ ug m}^{-3}$.

these levels can cause harm to the environment. However, sulphur in excessive amounts can have a deleterious effect on plant life.

The first visible evidence of SO₂ injury to plants is discernible in the foliage. The stems, buds, and reproductive parts of plants are visibly more resistant to SO₂ than foliar parts. It is important to stress the difference between acute, chronic, and subtle effects of SO₂ on plant life. Acute injury is caused by a rapid accumulation of bisulphite and sulphite. When the ultimate oxidation product, sulphate, accumulates beyond a threshold value that the plant cells can tolerate, chronic injury occurs. It is estimated that sulphate is about 30 times less toxic than sulphite (Thomas 1951).

Definitions vary for acute and chronic injury and for subtle effects caused by air pollutants and to avoid different interpretations for these terms with respect to SO₂, the following definitions will apply (Linzon 1978). Acute injury is macroscopic necrotic injury to plant tissue visible within hours or days following exposure to short-term (less than 24 hours) high concentrations of SO₂. Chronic injury is macroscopic chlorotic injury (sometimes changing to necrotic injury) to plant tissues usually developing over a long period of time (from over one day to one or more years) from exposure to variable concentrations of SO₂. Subtle effects are measured

physiological or biochemical changes, and/or reductions in plant growth or yield in the absence of macroscopic injury.

13.2.1 Acute Injury

Acute injury on broad leaves takes the form of lesions on both surfaces, usually occurs between veins, and is often more prominent towards the petiole. The injury is local. The metabolic processes are completely disrupted in the dead or necrotic areas with the surrounding green tissue remaining functional. The tissue immediately adjacent to the veins is extremely resistant. In some cases, injury can occur on the margins of the leaves. Young leaves rarely display necrotic markings, whereas fully expanded leaves are most sensitive to acute SO_2 injury. The oldest leaves are moderately sensitive. In monocotyledonous leaves the injury can occur at the tips and in lengthwise areas between the main veins. In conifers, acute injury usually appears as a bright orange-red tip necrosis on current-year needles, often with a sharp line of demarcation between the injured tips and the normally green bases. Occasionally the injury may occur as bands at the tip, middle, or base of the needles (Linzon 1972).

For acute injury to occur, other environmental and plant factors are important. These include sunlight, moderate temperature, high relative humidity, adequate soil moisture, and plant genotype and stage of growth. If these factors are not conducive to injury, the plants will escape harm even in the presence of doses two or three times higher than those noted above. Conversely, if the predisposing factors are especially conducive to plant injury, the SO₂ doses could be reduced.

13.2.2 Chronic Effects

Chronic injury appears as a yellowing or chlorosis of broad leaves. In perennial conifers, chronic injury affects older needles and appears as a yellowish-green colour, then changes to reddish-brown, starting at the tips and developing towards the base (Linzon 1969). The rate of metabolism is reduced in leaves displaying chronic injury.

Chronic injuries develop slowly on coniferous perennial foliage with the greatest increase in injuries in

the Sudbury sulphur-fume effects area occurring on the one-year old needles of eastern white pine trees. Continued chronic injury to perennial foliage of coniferous trees results in premature needle abscission, reduced radial and volume growth, and early death of the trees (Linzon 1971).

Long-term chronic effects on coniferous trees are related to a variety of SO_2 exposures which include short-term high concentrations, short-term and long-term periods of sub-lethal concentrations, and even SO_2 -free periods in which time the plant life can recuperate by translocating and assimilating accumulated sulphur. To correlate the chronic effects on forest trees with atmospheric SO_2 levels, it is preferable to use the average concentration for the total period of exposure, rather than the average of SO_2 fumigation periods only. Attacks by intermittent fumigations are unpredictable as to frequency of occurrence, concentrations of SO_2 , and duration of the fumigation at any particular location. Chronic effects develop slowly, and the response of the receptor is influenced by other environmental factors in addition to SO_2 . The vegetation affected is exposed throughout the entire growing season to the vagaries of the environment, (sun, rain, wind and drought) all which have an influence on plant response to SO_2 .

Atmospheric SO_2 may affect a forest ecosystem in various ways. Forest communities have evolved and become established through the selective pressures of the environment. The addition of a new pressure, such as increased atmospheric sulphur, can alter the delicate balance of the ecological system. This alteration may be beneficial or deleterious depending on the magnitude of the addition and the state of the receptor.

In the Sudbury area of Ontario, three large nickel smelters had previously discharged approximately 6000 tons of SO_2 per day into the surrounding atmosphere. Forest effects in the area were excessive with severe injury on trees occurring up to 25 miles northeast of Sudbury. Based on studies of over 6000 white pine trees on 42 sample plots during a 10-year period, (1953-1963) the Sudbury area of Ontario was segregated into three fume zones: Inner, Intermediate and Outer, (Linzon 1966). In the Inner Fume Zone, an area of about 720 square miles, white pine trees displayed both acute and chronic foliar injuries which resulted in reduced radial and volume growth and in excessive tree mortality. In the Intermediate Fume Zone, an area of about 1600 square miles, some chronic SO_2 injury was present, while in the Outer Fume Zone, atmospheric contamination was too dilute to cause visible injuries.

Table 13.1 shows the results of forest studies conducted over a 10-year period in the sulfur-fume effects area near Sudbury (Linzon 1971). Very little acute injury to current year's needles occurred in the Sudbury forests northeast of Sudbury. The greatest increase in foliar chronic injuries during the growing season was found to occur on the one-year-old needles. The continuous development of injuries on the older needles was reflected in early abscission of the oldest foliage, reduced radial and volume growth, and premature death of the trees. It is apparent that the chronic effects on forest growth were prominent where SO_2 air concentrations averaged 0.017 ppm (44 ug m^{-3}), the arithmetic mean for the total 10-year measurement period, and chronic effects were slight where SO_2 annual concentrations averaged 0.008 ppm (21 ug m^{-3}).

In the general area of West Bay (19 miles NE of Sudbury), SO_2 readings over 0.25 ppm occurred 8.56% of the time with the average SO_2 concentration for the total 10-year period being 0.045 ppm. There were 224 days with 'potentially injurious fumigations' (PIF) in the West Bay general area during the 10-year period or an average of 22 days during each growing season when acute injury to vegetation could occur. Both acute and chronic injury occurred in this area with the maximum concentration of SO_2 recorded being 2.5 ppm. However in the Portage Bay general area (25 miles NE of Sudbury) SO_2 readings over

0.25 ppm occurred only 1.1% of the time with an average SO_2 concentration for the ten years being 0.017 ppm. There were 23 PIF days during the 10-year period or an average of about 2 days during each growing season when acute injury to vegetation could occur in the Portage Bay area. Actually, observations after each potentially injurious fumigation revealed that acute injury occurred during 11 of the 23 PIF days, or only on an average of about one day per year. Chronic injury occurred for the most part in this area with the maximum concentration of SO_2 being 0.96 ppm. In the Grassy Lake general area (40 miles NE of Sudbury) there was on the average less than one day every two years that a potentially injurious fumigation occurred. No acute injury was observed in the Grassy Lake area with only chronic effects occurring. The maximum SO_2 concentration during the 10-year period at Grassy Lake was 0.52 ppm showing the importance of all concentrations of SO_2 in the development of chronic injury on coniferous evergreen trees.

In Czechoslovakia, Materna et al (1969) reported the occurrence of moderate chronic injury to foliage of spruce trees at Celna, under the influence of an average concentration of SO_2 of 0.019 ppm (50 ug m^{-3}) for the years 1966 and 1967. In this report the authors stressed the importance of both long-term concentrations of SO_2 and other environmental factors in producing chronic injury to plants.

Table 13.1 - Degree of Forest Effects at Various Distances from Sudbury Smelters¹

Forest Sampling Station (Distance and Direction from Sudbury)	Trees with Current Year's Foliage Injured in August 1963 (%)	Trees with One-Year-Old (1962) Foliage Injured June 1963 (%)	Trees with Two-Year-Old (1961) Foliage Lacking in Aug. 1963 (%)	Net Annual Average Gain or Loss in Total Volume 1953-1963 (%)	Annual Average Mortality 1953-1963 (%)	Degree of SO ₂ Damage	Average SO ₂ Concentration for Total Measurement Period 1954-1963 ² (ppm)		
19 miles NE (West Bay)	2.0	38.0	77.9	96.0	20.6	-1.3	2.6	Acute and chronic injury	0.045
25 miles NE (Portage Bay)	1.1	21.5	55.6	77.0	15.2	-0.5	2.5	Mostly chronic and little acute injury	0.017
40-43 miles NE (Grassy to Emerald Lake)	0.4	2.5	16.7	37.5	9.1	+1.8	1.4	No acute injury Very slight chronic injury	0.008
93 miles W (Lake Matinenda)	0.6	0.3	2.1	10.1	3.9	+2.1	0.5	Control No SO ₂ injury (Sturgeon Falls)	0.001
Correlation Coefficient (r)	0.96*	0.96*	0.93°	0.90°	0.94°	0.90°	0.81		
	* p 0.05		° p 0.10						

1 Linzon, 1971
2 Dreisinger, 1965, (1970).

Epiphytic lichens, which are perennial and evergreen are extremely sensitive to SO_2 because they are continually exposed to the gases in a polluted environment. In studies conducted on the occurrence of lichens at Sudbury (Leblanc et al 1972), the number of epiphytes found growing on Populus balsamifera trees was drastically reduced in zones where the growing season mean levels of SO_2 were over 0.02 ppm (52 ug m^{-3}) and slightly reduced in zones where the mean levels of SO_2 were over 0.01 ppm (26 ug m^{-3}). Similarly, in Sweden (Skye 1964) it was found that the survival of lichens was less in areas with an annual SO_2 concentration of approximately 0.015 ppm (39 ug m^{-3}) and in the Tyne Valley, England (Gilbert 1969) a low species diversity of lichens was reached when the annual average of SO_2 was above 0.016 ppm (42 ug m^{-3}).

13.3 Air Quality Standards for Sulphur Dioxide

In formulating air quality standards for SO_2 for a particular jurisdiction many factors must be taken into consideration. Foremost are the scientific criteria which describe the effects of SO_2 for given concentrations and time periods on exposed receptors. These criteria are generally assembled from information published in scientific and technical reports. The published data may be based on effects in the field caused by ambient atmospheric concentrations of SO_2 or

from experiments conducted under controlled environmental conditions.

Generally, the effects of SO_2 observed in the field, under natural conditions, provide the best basis for interpretation. Difficulties are encountered in attempting to extrapolate the results of experimental fumigations to natural ecosystems. The reasons for the difficulties are that the varying environmental conditions which occur out-of-doors are almost impossible to duplicate in experimental fumigations. The temperature, relative humidity, light quantity and quality, wind, soil moisture, receptor responsiveness, SO_2 concentrations, and presence of other air pollutants are continuously fluctuating in the field at the site of the receptor-environment interface.

Despite these difficulties, published data on artificial fumigation work indicated that effects on plant life were caused by some extremely low SO_2 doses. Conversely, the literature showed that some plants were notably resistant and could tolerate very high concentrations of SO_2 . For example, injury occurred on extremely sensitive strains of eastern white pine at a dose as low as 0.03 ppm SO_2 for 1 hour (Costonis 1971) whereas 3.0 ppm for 1 hour was required to cause minimal injury to Acacia pruinosa (O'Connor et al 1974). Many jurisdictions have an air quality standard for SO_2 close to 0.3

ppm for 1 hour which is 10 times higher than one of the lowest dose-responses reported and 10 times lower than one of the highest dose-responses reported.

In considering other factors, administrators may reduce current SO_2 standards. These other factors include:

1. Synergism, in which the concentration of SO_2 required to cause injury to receptors can be lowered significantly when combined with other air pollutants such as O_3 or NO_2 ; and
2. Acidification, in which the oxidation of SO_2 to SO_3 and hydrolysis to H_2SO_4 contributes to acidic precipitation which has the potential to cause effects on soils and plant life.

However, the present state of knowledge on the precise role that ambient levels of atmospheric SO_2 play in these two phenomena is incomplete.

Establishing satisfactory air quality standards for SO_2 are important for the protection of all receptors, including man, animals, vegetation, water and fish. Adequate air quality standards for SO_2 will help to prevent:

1. Acute injury to current year's foliage and chronic damage to forests which includes accumulation of excess sulphur in perennial foliage on trees, progressively increasing injuries to older foliage, early abscission of older foliage, reduced radial and volume of growth of trees, and premature tree mortality;

2. Killing of lichens and changes in the species of lichen populations in sulphur-polluted areas; and
3. Adverse effects on lake quality and fish populations caused by long range transport of sulphates which contribute to acidic precipitation.

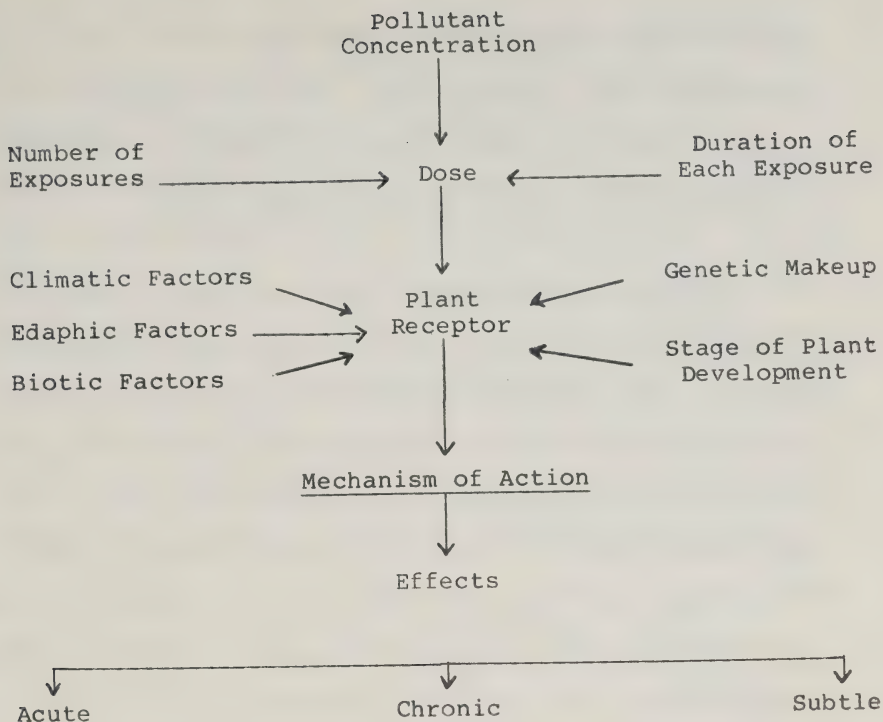
13.4 Ozone-Direct Effects on Vegetation

Visible injury to vegetation which was first reported in the vicinity of Los Angeles (Middleton et al 1950) in 1944 was one of the earliest indicators of photochemical oxidant air pollution. However, it was not until 1958 (Richards et al) that ozone, now recognized as the major component of photochemical smog and one of the most damaging of all air pollutants affecting vegetation, was identified as a direct phytotoxicant in the smog complex. The other photochemical oxidants which are also classed as secondary air pollutants include nitrogen dioxide and the peroxyacylnitrates. Although both the latter pollutants have been scientifically documented as phytotoxicants, their overall significance with respect to transboundary movement and direct vegetation effects in areas remote from the major smog centres either is of minor importance or is not sufficiently documented to warrant consideration in this document. As such, the information pertaining to transboundary oxidant effects in this section will focus entirely on ozone.

Visible foliar injury resulting from exposure to atmospheric ozone usually is apparent either as pigmented lesions, upper surface bleaching, bifacial necrosis or as

general chlorosis (Hill et al 1970). The injury is characteristically interveinal in nature; however, in many species the lesions can become more prevalent along the sides of the larger veins and actually develop over the smaller veinal tissue. The development of symptoms also is very closely associated with tissue age, with leaves ranging from 65-95% of full size being the most sensitive. Young, recently developed leaves are considerably more resistant, as in most cases, are older, fully mature leaves. This relationship between tissue age and ozone sensitivity is of significant diagnostic value, as injury location on the leaf or leaflet usually will follow a pronounced pattern associated with the developmental progression of the plant or leaf. Multiple exposures to ozone can complicate this symptomatology as younger leaves become more sensitive and previously sensitive leaves become increasingly more resistant. Also affecting the injury syndrome are a host of environmental factors which in effect control the overall response of any group of plants.

A conceptual model depicting these factors and their relationship with injury expression has been developed (National Academy of Science, 1977) and is shown below.



Included in this model are the parameters of concentration, duration, and exposure frequency which together constitute pollutant dose. There have been a number of publications (Heggestad and Heck 1971, Heck and Tingey 1971, and Larsen and Heck 1976) which have dealt specifically with the relationship between time, concentration and plant response; however, the most extensive coverage of this matter was presented in a 1975 Canadian National Research Council Criteria Document (Linzon et al 1975). A time-concentration scatter diagram based on 5% acute foliar injury development for over 100 plant species and varieties was developed and revealed a threshold dose for injury to the most

sensitive plant species of 10 and 3 pphm for 1 and 8 hour exposure periods, respectively. The corresponding concentrations for plant species considered intermediate in response were 20 and 10 pphm respectively.

Although the effects of ozone exposure on crop yield or productivity have not been as extensively documented, there are, nevertheless, numerous reports on this topic. The assessment of yield parameters is complicated by the ubiquity of ozone exposure and the difficulty in establishing suitable ozone-free control plots. These difficulties have been at least partially overcome by the use of open-top field chambers (Heagle et al 1972, McLean and Schneider 1976, and Leone and Green 1974) and by providing exposure protection through the use of experimental anti-ozonant chemical treatments (Hofstra et al 1978, Manning et al 1974, and McClenahan 1979).

Although ozone formation was traditionally associated with urban atmospheres (smog) due to the input of precursor pollutants in these areas, it is now recognized that long range transport by regional air mass movements can result in significant ozone episodes and vegetation injury in remote rural areas (Stasiuk and Coffey 1974, Wolff et al 1977, and Hayes and Skelly 1977).

In Ontario the first indication of transboundary ozone movement across Lake Erie was documented by Mukammal in 1960 following extensive work on the relationship between the incidence of weather fleck on tobacco and meteorological conditions associated with the buildup of ozone. Since then a number of large-scale meteorological investigations (Yap and Chung 1977, and Anlauf et al 1975) have documented these early findings and have shown that high ozone levels generally are associated with regional southerly air flows which have passed over numerous urban and industrialized areas of the U.S. and which, as they move across the lower Great Lakes, undergo rapid dispersion as they encounter unstable conditions near the northern shore of Lake Erie. Contributing to these influx patterns are the more localized downwind urban effects which can add to the already high background levels.

Nowhere in Canada has the problem of ozone injury to vegetation been as extensive or as well-documented as in the southwestern portion of the Province of Ontario. Ozone induced 'weather fleck' on the foliage of sensitive tobacco cultivars was first observed in this area in 1954 (Macdowall et al 1963) and, since that time, ozone injury has been documented on many different crop species (Ormrod et al 1980).

In an effort to highlight the severity and extent of crop injury or yield loss resulting from exposure to ambient ozone in Ontario the following summary has been prepared. Although not all of the information which is presented has been published in the scientific literature it has nevertheless been scientifically documented by government agencies or university departments working under assessment mandates or research contracts.

13.4.1 White Beans

The bronzing or rusting of the foliage of white beans has been observed since as early as 1918 and was originally classed as a non-parasitic disease and referred to as sunscald (Weaver and Jackson 1968). In 1961 the disorder was reported (Clark and Wensley 1961) throughout southwestern Ontario and the resultant defoliation and pod abortion was estimated to have resulted in a loss of approximately 600 pounds of beans per acre in severely affected fields. In 1968, following extensive field work in 1965 and 1967 the symptomatology of the disease was more thoroughly documented by Weaver and Jackson (1968) and the disorder was found to be associated with the occurrence of elevated levels of atmospheric ozone pollution. The symptoms were described as follows:

The symptoms first appear sometime between flowering and normal senescence. The older leaves become senescent and absciss prematurely; the younger, fully expanded leaves develop

a bronze-coloured necrotic stipple which is confined to the upper surface of the lamina. The stipple may occur in combination with chlorotic symptoms as well. Immature leaves are generally not affected. The developing bean pods may show striate, necrotic lesions along the fibers of the pod sheath. Reduced seed set, pod yellowing and abscission are also associated with the disorder.

In an effort to assess and compare the annual severity of ozone injury on sensitive white beans, personnel from the Phytotoxicology Section, Ontario Ministry of the Environment have conducted visual assessment surveys throughout the major production areas in southern and southwestern Ontario since 1971.

In the 10 years of study over 300 visual ratings have been made with injury severity ranging from negligible amounts to severe bronzing and associated premature foliar loss. These studies also ruled out any differences in varietal sensitivity and confirmed that the problem was widespread throughout the bean production areas with no one area being any more severely affected than any other.

Studies utilizing chemical protectants against ozone injury have helped to provide information on the economic relevance of the bronzing disorder. In one case a 13% yield increase was associated with the reduction in bronzing severity (Curtis et al 1975), while in another study yield increases of up to 38% were realized (Hofstra et al 1978).

13.4.2 Tobacco

"Weather fleck" of tobacco so named because of its relationship to certain weather conditions has been recognized as an ozone induced disorder in Ontario since 1954 (Cole and Katz 1966).

The symptoms appear on fully expanded leaves, the younger and older leaves being more resistant. They start on the upper leaf surface as greyish, water soaked lesions which become light ivory to tan-brown in colour with time. In more severe episodes the lesions can coalesce into larger flecks or spots and become bifacial with increasing severity. Successive episodes of ozone fumigation result in new lesions appearing on healthy tissues of recently injured, fully expanded leaves as well as on fully expanded leaves higher on the main stem.

Although considerable success has been achieved in Ontario, in the area of breeding resistance into commercially acceptable varieties, losses associated with this high value crop continue to be a problem in tobacco production (Ormrod et al 1980). In 1972 and 1973 economic losses resulting from decreased leaf weight and quality were estimated at 1.0 and 1.35 million dollars respectively. Although economic estimates of crop loss have not been made since that time, a visual assessment

of foliar injury severity consisting of 33 separate observations throughout the major tobacco production areas of southern Ontario was conducted in 1977 by Phytotoxicology staff from the Ontario Ministry of the Environment, and confirmed the presence of foliar injury development ranging from less than 1 to 20% on flue-cured species and up to 88% on burley types. In view of these findings and considering the continued increase in the dollar value of the crop in recent years, the current annual economic loss probably is in the 2-3 million dollar range.

13.4.3 Potatoes

The foliar symptoms referred to as "speckle leaf" on this crop usually appear sometime after mid-July when the plant has flowered and the tubers are developing. As the demands for photosynthetically produced nutrition at this time are at their peak the potential for adverse yield effects is great. The symptoms appear either as a blackened stipple or flecking on the upper leaf surface which can coalesce and become bifacial necrotic lesions or as undersurface, irregularly sized, silver-grey lesions which also can become bifacial as they increase in size and severity.

Although the adverse economic effects of the injury to this crop have not been thoroughly documented in

Ontario, the foliar symptoms have been recognized as being ozone induced since as early as 1954 (Johnston 1972) and in several later years (McKeen et al 1973). Yield losses are suspected to be quite high on several of the most sensitive varieties. Staff from the Ontario Ministry of the Environment have conducted annual foliar injury assessment surveys throughout the major production areas since 1977 and in that time have examined over 130 plantings and recorded foliar injury development ranging from less than 1 to 30% leaf area. A more detailed yield assessment which is also exploring the possibility of ozone-disease interactions is currently in progress and should provide a comprehensive outline of the adverse effects of the foliar symptoms on crop yield.

13.4.4 Grapes

Dark brown to black spotting or stipple of grape leaves was first reported in California (Richards et al 1958) and was attributed to the presence of atmospheric ozone in the grape production areas. The symptoms which include premature leaf senescence and abscission and commonly called "brown leaf disorder" have been reported to be widespread on several American cultivars and French hybrids grown in vineyards throughout upper New York State (Shaulis et al 1972). In 1973 and 1974 (Kender and Carpenter 1974), a large number of grape cultivars and hybrids in both New York State and Ontario were assessed

for oxidant injury severity and these findings prompted an in-depth 4 year study by the University of Guelph to ascertain the extent of the problem in terms of the severity of foliar injury development and potential adverse effects on crop yield and quality. Although these results have not yet been published they did confirm that the "brown leaf" disorder of grapes is a readily recognizable problem in Ontario each year and that, in general, the most severe injury can be found in the Simcoe vicinity, followed by southwestern Ontario and the Niagara region, in that order. The failure of the anti-ozonant chemical treatment to offer sufficient protection from foliar injury development negated the efforts to quantify adverse yield and quality effects. As such, the relationship between foliar injury development and yield parameters remains unresolved for this crop.

13.4.5 Other Crops

Other Ontario grown crops which have been shown to display varying degrees of foliar ozone injury include: onion, cucumber, celery, pumpkin, squash, and radish. PAN-type oxidant symptoms also have been recorded on the undersurface of the leaves of sensitive tomato cultivars throughout the major production areas of southern Ontario since 1972. Unfortunately until such time as ambient monitoring for this component of the photochemical

oxidant complex is completed, the injury must be referred to as PAN-type.

13.4.6 Summary - Ozone

Foliar injury development and associated crop yield losses resulting primarily from the transboundary movement of photochemically produced ozone into Ontario have been well documented and represent a very significant impediment to the agricultural economy of this Province. On the basis of the known response of other woody and ornamental species relative to that of sensitive crop species, it is possible that other sectors of the economy both in Ontario and in other regions of Canada have suffered to some degree due to losses either in aesthetic appearance or general productivity.

In a review of ozone effects on plants which was published in 1975 by Reinert the effects which can be expected from repeated exposures to ozone in excess of 0.08 ppm (1-hr average) are losses in plant fresh and dry weight which may approach 15-30%.

13.4.7 Ozone: Acid Precipitation Interaction

There have been few experimental studies designed to explore the possibility of interacting effects between the two major pollutants associated with long-range, trans-

boundary air mass movements (ozone and acidic precipitation). There have, however, been several reports that stress the importance of both sulphur (Adedipe et al 1972) and nitrate (Menser and Street 1962, Brewer et al 1961 and Ormrod et al 1973) nutrition in determining plant response to ozone. As plants can derive significant portions of their nutrient requirement from foliar uptake the potential for ozone-acid precipitation interactions must be considered.

Although experimental study of this concept is still at an early stage there are indications based on controlled fumigations under simulated field conditions (Jacobson et al 1980 and Shriner 1978) that both nitrate and sulphate, the two major components of acidic precipitation, can have an interacting effect on plant response to ozone and must therefore be considered in any field evaluation of crop response to ozone fumigation. Jacobson et al (1980) using open-top exposure chambers with field-grown soybeans, compared growth and yield between three pH levels of simulated rain (pH 2.8, 3.4, and 4.0) and two levels of ozone (0.03 and _ 0.12 ppm). Results demonstrated that ozone depressed both growth and yield of soybeans with all three rain treatments, but that the depression was greatest with the most acidic rain.

References - Chapter 13

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14. ACIDIC PRECIPITATION - DIRECT EFFECTS ON VEGETATION

Acidic precipitation can affect terrestrial vegetation either directly or indirectly. Direct effects are a consequence of the interaction of the acidic solution with the surfaces of the above ground portions of the plant. Indirect effects are a consequence of the acidic solution inducing changes in the plant environment, most commonly the rooting medium.

Such a distinction may appear artificial in resolving the question of plant response to acidic precipitation. Since a plant is a dynamic entity, a stimulus that induces a negative response on one hand will more often than not cause the organism to compensate by drawing upon the resources available to it in the environment. The availability of such resources will influence the magnitude of the initial response.

Nevertheless, there have been numerous investigations conducted in an attempt to resolve how a plant will react to the direct contact of an acidic solution. The most common parameter measured is the degree and type of injury caused to a vegetation surface, usually the leaf, together with a measurement of a physiological or morphological response. A second interaction mechanism examined concerns chemical measurements. Such include the degree of foliar leaching and changes in the

chemical composition of the plant tissue. Other investigations have examined host-parasite relations and fertilization success.

For the most part, such experimentation involves the application of acidic solutions to the test organisms. The solution may be dilute mineral acid(s), simulated rain prepared with salts and acidified by mineral acids or collected ambient rain further acidified. Application techniques vary from simple hand spraying in a greenhouse to highly controlled environment chambers with turntables and overhead nozzles. Rates, frequencies and exposure durations vary as do test species. Unrealistically high acidities are usually employed, as compared to ambient rain, to shorten the time frame necessary to observe a response.

Extrapolation of laboratory simulation results to natural situations would be very difficult. Certainly there has not been any clear evidence of ambient rainfall acidity conditions causing damage to vegetation or either promoting or inhibiting productivity of forests or crop plants. The complexity of environmental variables makes it difficult to obtain such evidence at least if acidic precipitation conditions do not worsen.

It is necessary to encourage continuing research on the interaction of acidic precipitation and vegetation.

Such an approach is the only one feasible at this time and results so obtained can direct field investigations. Much information is already available and is reviewed in the following sections.

14.1 Leaching of Foliage Constituents

Enhanced leaching of foliage constituents, notably inorganic cations, by acidic rainwater is an often cited effect on vegetation by acidic precipitation. (Ferenbaugh 1975, Glass et al 1979, Jacobson 1980, Likens et al 1977, Overrein 1977). Two main approaches have been used to evaluate this effect. Application of acidic solutions to plant tissue by various techniques is followed by an analysis of the solution. Changes in chemical composition are noted. An alternative approach has been to collect precipitation after it has interacted with the plant tissue under ambient conditions. Comparisons to incident precipitation chemistry are then made.

The first approach has the advantage of being able to isolate one variable, namely H^+ ion concentration. Observed response can be related to this variable. The second approach lacks this advantage. It further lacks the ability to separate the effect of acidic precipitation from that of the various other pollutants. Variables due to site location, species and physiological

condition of the vegetation compound the difficulties. Nevertheless, the two approaches can be complementary as field observations can be interpreted in light of experimental observations.

The role and importance of rain, dew and mist in leaching of plant tissue is discussed in an excellent summary by Tukey (1980). An understanding of this process is crucial in consideration of acid precipitation induced changes.

A wide variety of organic and inorganic substances can be leached from foliage and the process is essential to the proper growth and development of plants. Cations from exchange sites on the cuticle or from the translocation stream within the leaf are exchanged for H^+ ions in the leaching solutions. Losses from the cells are not significant except in cases accompanied by visible injury. Young, vigorously growing tissue will have fewer exchangeable cations and consequently losses will be smaller than from more mature tissue.

Normally, carbonic acid derived from CO_2 in the rain is a source of such H^+ ions as well as the carbonate anions. Cations lost from the tissue will be in the form of alkaline carbonates. Leaching induced losses from foliage is an important mechanism of nutrient cycling in an ecosystem. Nutrients in excess of cell metabolism requirements are returned to the soil store.

However, under present conditions of rainfall acidity, carbonic acid will not occur. The anions are sulphate and nitrate and there is an elevated concentration of H^+ ions. Consequently, alterations in the foliage leaching process and the form of recycled nutrients are highly probable. The net effects of such alterations in the plant or the community are under investigation.

Cation losses from foliage have been found to increase in response to increasingly acidic solutions being applied. Wood and Bormann (1975) found such increased losses for Ca^{++} , K^+ and Mg^{++} from pinto bean and sugar maple. Losses accelerated if the tissue was injured by extreme acidity. Na^+ losses did not follow the pH trend while Ca^{++} and K^+ were the cations most affected.

In a similar experiment, Fairfax and Lepp (1975) found Ca^{++} losses from tobacco to increase with increasing acidity. However, Mg^{++} was unaffected and K^+ losses actually decreased. Damage to a K^+ root uptake mechanism is hypothesized.

Leaf litter will also be leached by acidic solutions. Fairfax and Lepp (1976a) noted accelerated losses of Na, K, Ca, Mg, Zn and Cu with increasing treatment acidity. Substantial Mg loss was attributed to

chlorophyll breakdown. Lee and Weber (1980) found that the acidic precipitation simulant applied to a reconstructed forest (lysimeter) was neutralized after passing through the litter. SO_4^- concentration increased after percolating through the litter. Ca^{++} losses increased with increasing SO_4^- concentration.

In the Norwegian SNSF project acidified groundwater was applied to spruce canopies through overhead irrigation, (Abrahamsen et al, 1976). Leaching losses of K, Ca, and Mg were stimulated at low pH whereas, Na^+ , NH_4^+ , NO_3^- , Cl^- and PO_4^{+++} were not dependent on pH. In these experiments it was also noted that Ca^{++} and Mg^{++} were absorbed by the spruce crowns at high pH. This is due to the use of groundwater with high concentrations of such nutrients.

Forest floor mosses have also been found to lose more nutrient cations when leached with acidic solutions (Fairfax and Lepp (1976b)). Pretreatment with NO_2 enhanced losses. Since mosses and lichens can be highly dependent on the atmosphere for nutrients, acidic precipitation leaching may be a significant deleterious effect.

Aside from such simulated acidic precipitation leaching studies, there has been much effort directed towards comparing ambient precipitation quality before

and after forest canopy interactions. Such studies invariably address rainfall and throughfall acidity and how it related to other observed alterations.

Eaton et al (1973) found that numerous nutrient cations and anions were enriched in throughfall under maple, beech and birch at the Hubbard Brook Experimental Forest. The ratios of different nutrients varied with the tree species. The tree canopies were also found to neutralize the acidity of precipitation. Ninety-one per cent of the incident H^+ ions remained in the canopy while 27% of the cation leaching was attributable to H^+ ion exchange.

Cole and Johnson (1977) observed an increase in pH of throughfall in a Douglas Fir forest in Washington. Continuous conductivity and pH measurements suggested that most of the canopy leaching occurs during the early stages of an event. However, since throughfall pH remained a unit higher than incident rain pH through an event, H^+ ion-cation exchange was continuous. During a light drizzle, incident rain pH fell below 3 but throughfall remained above pH 5.

McColl and Bush (1978) observed a decrease in acidity and an increase in other ions upon throughfall in a Eucalyptus forest in California. They concluded that the contribution of ions to throughfall was a result of a wash-off of dry-impacted pollutants. Acidity was being neutralized by particulates.

In contrast, studies in the vicinities of SO_2 sources, such a natural gas processing plant, indicate an increase acidity upon throughfall (Baker et al 1977). Deposition of SO_2 to the canopy contributes to this increase.

While dry deposition of pollutant gases and particulates will have a definite influence on throughfall chemistry; the interacting tree species may have a similar influence. Studies contributing to the Norwegian SNSF project note such differences (Bjor et al 1974). The pH of incident precipitation was in the range 3.85 to 5.80 while throughfall pH under spruce, pine and birch was in the range 3.35 to 7.00. Spruce and pine canopies enhanced concentrations of strong acid, Na^+ , Mg^{++} and SO_4^- Birch canopies reduced strong acid concentration while enriching Mg^{++} . A strong correlation between Mg^{++} and SO_4^- in throughfall suggests acid leaching of foliar magnesium.

The observed increase in strong acid upon throughfall under the conifers is interesting in light of some recent observation made by Hoffman et al (1980). Throughfall under a chestnut and oak canopy in Tennessee had reduced strong acid concentration, however, total acidity was conserved. Weak acids derived from the foliage are postulated to be compensating for strong acid losses.

The foregoing studies do demonstrate one common point; precipitation-vegetation contact results in a repartitioning of chemical components. The direction of this exchange depends on availability for exchange of a given component within each system. Throughfall studies demonstrate an enrichment of inorganic ions in the precipitation after contact with vegetation. Experimental evidence demonstrates increasing losses of cations if the H^+ ion concentration in the leaching solution increases.

If such a leaching process is a simple exchange of H^+ ions for cations then the fate and effect of increasing H^+ ion concentration in plant tissue is a question that deserves some consideration. If increasing rainfall acidity is providing excess H^+ ions for foliar cation exchange, exchangeable foliage cations may be depleted. However, if the leached elements are in an available form then root uptake will ameliorate these losses. Thus soil conditions would have considerable influence. Soil would also be a factor in determining availability of leachable ions to foliage and thus the degree of neutralization of throughfall acidity.

14.2 Foliar Injury, Physiological Alterations
and Yield Effects

A considerable body of literature exists concerning foliar injury symptoms induced by acidic solutions. Changes in productivity are often assessed in conjunction with such observations. All such observations have been made under experimental-acidic rain simulation conditions. There has not been any conclusive report of ambient acidic precipitation having a deleterious effect on vegetation in the field. This is of course apart from areas close to point sources of sulphur dioxide emissions.

Efforts to assess changes in forest productivity as a result of the deposition of long range transported acids generally have been unable to show a decrease or have been inconclusive. (Andersson et al 1980, Cogbill 1977, Whittaker et al 1974).

Difficulties arise in attempting to observe tissue damage or reduced productivity of forests and crops resulting from presently occurring ambient precipitation acidity. The environment is highly variable, with any number of positive or negative influences to vegetation. These would be very difficult to isolate from effects due to precipitation chemistry. Long-term deleterious effects to forests would probably follow soil degradation.

Experimental studies with acidic solutions applied to vegetation have resulted in a number of observations of injury symptomatology. The pH of the test solution must usually be 3.5 or lower to elicit such responses. However, numerous other variables, aside from treatment solution pH must be considered. Species differences, with their associated morphological features, physiological condition and ability of the plant to neutralize acid will all influence degree of injury. Treatment frequency, duration and intensity, solution chemistry and environmental conditions before, during and after treatment can all contribute to variability in response.

One attempt to evaluate a dose-response relationship was made by Jacobson and van Leuken (1977). They found that injury depended on treatment duration in addition to simply treatment acidity. Consequently the following summary of experimental evidence for response of various species to acidic solutions should be viewed in light of the variable treatment conditions employed.

Wood and Bormann (1974) misted greenhouse grown (loam soil) yellow birch seedlings with acidified (H_2SO_4) distilled water. Intensity was equivalent to 0.5 cm of rain over 6 hours per week and for either 11 or 15 weeks. Necrotic spotting was observed at treatment pH 3.0 and 2.3. Leaf curling, shortening and death was observed at the pH 2.3 treatment level. Seedlings which

were exposed to mist at an early life stage (cotyledon) died with pH 2.3 treatment while older seedlings survived.

Ferenbaugh (1976) sprayed greenhouse bean plants with H_2SO_4 acidified distilled water. Daily application was made until leaves were thoroughly wetted. Duration of experiments was not reported. Histological, physiological and biochemical perturbations were assessed. At pH 2.5, shortened internodes and increased budding were observed. Leaves were smaller with rolled-under margins. At pH 2.0 and 1.5, necrosis and premature abscission occurred. At pH 2.5 and less, cells, intercellular spaces and starch granules in the chloroplasts were smaller. Bundle sheath parenchyma and epidermal cells were acidified to less than pH 4. Chlorophyll concentration was reduced at pH 2.0 but this could be due to the high incidence of necrosis. Sugar and starch content was reduced at pH 2.5 while photosynthetic rate increased with treatment acidity. Biomass especially of roots, was reduced by the acid treatments.

Evans et al (1977a, 1977b) sprayed bean and sunflower plants with a simulated rain solution acidified with H_2SO_4 . The daily 6 minute treatment was a rate of 0.78 cm/hr. Foliar perturbations were examined by electron microscopy. Injury was observed at pH 3.1 and was progressively more severe as pH of treatment

decreased. The injury consisted of collapsed adaxial epidermal cells while sites of injury were concentrated near trichomes and stomata. Lesion size increased with repeated treatment. Chlorosis was also noted.

Evans et al (1978) exposed 6 hybrids of poplar to a simulated rain solution acidified with H_2SO_4 . Five, daily, 6 minute applications were made at a rate of 7.2 mm/hr. Several clones were injured after 5 days of the pH 3.4 treatment. Severity of injury increased with treatment repetition and increasing acidity. A single treatment at pH 2.7 or 2.9 produced lesions, chlorosis followed by necrosis and some clones exhibited a red coloration at the lesion periphery. Two clones developed galls. Lesions were concentrated near stomata and vascular tissue. Very young and older leaves were least affected. The differential response of the clones is of interest.

The differential response of a number of species was examined by Evans and Curry (1979). Soybean, spiderwort, pin oak and bracken fern were subjected to a simulated rain solution acidified with H_2SO_4 . Plants were grown and treated in chambers. Exposure was daily for 20 minutes and for 10 days (twice daily for spiderwort). Between 2.3 and 5.0% of the leaf surface of spiderwort was injured after 9 days at pH 2.3. Cell hypertrophy occurred. Eighteen per cent of the bracken fern pinnae

surface was injured after 10 days at pH 2.5. Pin oak leaves had less than 1% of the surface area injured after 10 days at pH 2.5. Gallings was observed. Soybean was injured (6-7% of leaf area) after 6 days at pH 2.7. Younger leaves were more sensitive. Leaf surface characteristics are probably important in delineating differential sensitivity of species to acidic solutions.

In an attempt to elucidate the effect of treatment variability, aside from H^+ ion concentrations, Jacobson and van Leuken (1977) conducted a variety of simulation experiments. Test species, frequency and duration of application as well as chemical composition of simulant were examined. Typical injury symptoms consisted of necrotic lesions. Herbaceous plants were injured after 1 minute at pH 2., 1.5 hours at pH 3.0, 3 hours at pH 3.2 and 9 hours at pH 3.4. The presence of additional ions (approximating natural rain) in the acid solutions did not alter symptomatology. Repeating the treatment or prolonging the duration of the treatment resulted in increased injury. Herbaceous species appeared to be more susceptible to lesion injury than conifers.

Irving (1978) investigated quantity of acidic rain required to produce injury in soybean. Simulated acidic rain solutions were applied to chamber grown plants in a quantity that ranged from 0.65 to 9.35 cm over 4 days. Test solution pH was either 5.6 or 3.0. Necrotic lesions

occurred after as little of 2.0 cm of the simulant at pH 3.0. All plants were injured after 7.0 cm of this solution. Chlorosis was also observed.

Hindawi et al (1977) misted greenhouse grown bean plants with a simulated rain solution acidified with H_2SO_4 . Treatments lasting 45 minutes were applied weekly for 6 weeks. Harvesting occurred after 8 weeks. Injury occurred at treatment pH 2.5 and 2.0 but not at 3.0 and higher. Symptoms consisted of bronzed spotting to bifacial necrotic pitting. Decrease in chlorophyll concentration and dry weight occurred with increasing treatment acidity. Foliar concentrations of N, P, Mg and Ca declined with increasing treatment acidity, K was unchanged and S accumulated. (S accumulation was observed when treatment frequency was 5 times per week.)

Perhaps the most comprehensive investigation conducted to assess injury susceptibility and yield response to acidic precipitation solution was conducted at the Corvallis (Oregon) Environmental Research Laboratory (Lee et al 1980). Thirty-five cultivars of crop plants were grown in field chambers. H_2SO_4 acidified simulated rain solutions were applied at a rate of 6.7 mm/hr., 1.5 hrs/day and 3 days/wk. Date of first occurrence of injury was noted and yield and leaf area injured assessed at harvest. Of the 35 cultivars used, 31 were injured at pH 3.0, 28 at pH 3.5, and 5 at pH

4.0. Yield data was generated for 84 treatment combinations; 28 cultivars grown to maturity, multiplied by the 3 acid treatments. Of these, 32 combinations had neither yield effect or injury, 30 combinations had injury without yield effect, 6 combinations had yield effects without injury and 16 combinations had both yield effect and injury. Yield was enhanced in 7 and reduced in 9 of the 46 combinations showing injury. Yield reduction does not necessarily follow injury. Monocotyledons as a group were less susceptible to injury. Yield inhibition occurred only in dicotyledons. The variable response of different crop species to identical treatments with acidic rain solutions was demonstrated in these experiments and is of special interest.

Vegetation other than vascular plants has been investigated with respect to acidic precipitation. Sheridan and Rosenstreter (1973) treated moss (Tortula ruralis) with a sulphuric acid mist (pH range 1.0 to 6.0). Treatments occurred every 48 hours for 8 treatments. Chlorophyll content declined with increasing acidity with rapid decline below pH 2.0. Chlorophyll a was preferentially degraded. This was accompanied by a decline in photosynthetic rate. Respiration rate declined only below pH 2.0.

Lichens are frequently cited as sensitive to air pollution, especially SO₂. Robitaille et al (1977)

working in the vicinity of a copper smelter concluded that stemflow acidity is only second to SO_2 as an agent responsible for the lack of lichens near sources of acidic air pollution.

Plants such as mosses and lichens, which have a significant dependence on the atmosphere for nutrients, may be especially sensitive to acidic precipitation. These plants would not have the luxury of soil neutralizing their supply of nutrient solution.

14.3 Other Effects

Fertilization may be affected by acidic solutions contacting the gametes. In plants such as bracken fern, the spermatazoids require a moisture film to reach the archegonia. Evans and Bozzone (1977) examined the effects of acidic solutions on reproduction in bracken fern. The acidity of the test solution was maintained by a citrate-phosphate buffer. Motility of spermatazoids was found to decline when acidity increased. The percentage of sperm motile after a 2-4 minute contact with the test media was as follows; 65% at pH 5.8, 2.2% at pH 4.2 and 0% at pH 3.2. Fertilization success as measured by number of sporophytes produced was reduced as a result of sperm immobilization. Addition of sulphate further suppressed sperm motility and fertilization. Subsequent experiments (Evans and Bozzone 1978) showed that NO_3^- and Cl_1^- ions had effects similar to SO_4^- .

Kratky et al (1974) investigated the cause of seedless tomato fruits in the vicinity of a degassing volcano in Hawaii. Pollen germinated in distilled water but not in rainwater that had a pH of 4.0. Dilute HCl (pH 4.0) greatly reduced germination, however, neutralizing the rainwater with NaOH to pH 5.7 did not improve on pollen germination. Organic compounds in the rain were suspected as causal agents for the inhibition.

Masaru et al (1980) tested the effect of acidity on pollen tube elongation in Camellia pollen. Tube elongation was suppressed when the pollen was sown on to sugar and agar plates with a pH of less than 3.2. Tests with HNO₃, H₂SO₄ and HCl showed near identical effects.

Shriner (1978) examined the effect of spraying crop plants with acidic solutions on pathogen infection. Several host-pathogen systems were investigated and results were variable. While acidic solutions may predispose some plants to pathogen infection, the acidity may also reduce the virulence of the pathogen.

Shriner (in press) noted reduced nodulation in leguminous plants when treated with an acidic rain solution. While soil acidification can account for this reduced activity of Rhizobium, it was noted that nodulation was also reduced in treatments where only the foliage was sprayed (i.e., soil covered). Repeating acid exposures further reduced nodulation.

Finally, while erosion of leaf cuticular waxes is cited as one of the potential adverse effects of acidic precipitation, it is notable that such could not be detected in conifer needles subjected to a pH 2.5 simulant in the Norwegian SNSF experiments (Horntvedt et al 1980).

14.4 Summary

While there is a considerable evidence of deleterious effects to vegetation resulting from acidic precipitation; such evidence comes almost exclusively from experiments. In such treatments, the pH of the simulant required to produce an effect is usually far below that which is encountered under ambient conditions. It should be noted that there is no conclusive documentation of any direct effects on vegetation occurring in the field as a result of exposure to ambient, region-wide acidic precipitation.

In experiments where the simulant approaches the acidity of ambient rain (pH 4.0) the injury to the crop plants was very slight (Lee et al 1980). It is unlikely that it will be possible to detect injury as a consequence of rainfall acidity in nature at the present time. The acidity is insufficiently high and observations are complicated by the variety of other causal agents, both anthropogenic and natural.

While leaching of foliage constituents will be accelerated by an over-abundance of H^+ ions in the leaching solution, the net effect of this may simply be a higher rate of recycling of available nutrients to the soil. Measurements of throughfall in regions subjected to acid rain are difficult to interpret. Dry deposited gases and particulates will be indistinguishable from leached components and, of course, there is the problem of controls in such field investigations.

Direct deleterious effects on vegetation as a result of acidic precipitation may well be occurring. It will require continued research to reveal the degree of risk at current levels of acidity, the threshold for these harmful effects, and the benefits, if any of reductions in acidity of precipitation. The indirect effects, those mediated through the degradation of soil quality may be of primary concern if acidic precipitation continues for many decades.

References - Chapter 14

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15. TRANSBOUNDARY AIR POLLUTION

DIRECT EFFECTS OF

ACIDIC PRECIPITATION ON SOILS

15.1 Introduction

Long range transport of air pollutants such as sulphur dioxide and nitrogen oxides have lowered the pH of precipitation in North America. The pH of rain in equilibrium with atmospheric CO_2 is approximately 5.6. In Ontario the average pH of the rain is 4.2, however episodes have occurred with acidity levels as low as pH 3.2.

Soil is an extremely complex entity and its development involves climatic factors and microorganisms, as well as relief and water regimes acting through time on geological material.

The direct effect of air pollution, in the form of acidic precipitation on soil, will be discussed with regard to:

- I experimentation on soils in the field or laboratory with simulated acidic precipitation;
- II the effects of acidic precipitation on local soils from a point-source;
- III changes in the soil caused by acidic precipitation in nature;

IV models and pedological theories with regard to acidic precipitation.

A summary of the research to date will conclude the report.

15.2 Experimentation with Simulated
 Acidic Precipitation

15.2.1 Cation Leaching

Overrein (1972) exposed a 40 cm deep podzolic forest soil to 500 mm/mo simulated acid rain (pH 2.0-6.0) in a series of lysimeter investigations. After 40 days a steadily increased leaching of Ca became apparent when water at pH 4.3 was applied to the soil in contrast with the control (distilled water), which showed a low constant rate of leaching. Overrein found only slight increases in leaching at pH's greater than 4.0 on several soil types. Below pH 3.0 leaching was rapidly increased.

Wiklander (1973/74) has found, through experimentation, that acidification of soil caused base saturation to decrease markedly. Wiklander believes that the replacement of base cations is caused by H_3O^+ in the infiltrating precipitation. In another experiment Wiklander (1975) leached a podzol with an H_2SO_4 solution of pH 3.56 from below, at 6 ml/cm^2 per hour. The experiment included treatments with H_2SO_4 and neutral salts as well as salt solutions without H_2SO_4 . It was found that

salts in the leachate caused a decrease in soil pH indicating replacement of H^+ and Al^+ from the soil and a decrease of the net loss of Ca and Mg compared to H_2SO_4 .

In their experiments in Norway, Abrahamsen *et al* (1976) found that increasing the acidity (pH 6.0 to 2.0) of the simulated acid rain in field plots reduced the content of exchangeable metal cations and the base saturation in the top (organic) layers of podzol soils. Less podzolized soils were influenced less by acid rain. In a 1977 report Abrahamsen *et al* again stated that simulated rain of pH 3.0 resulted in a significant reduction of base saturation. Acid rain applied at the rate of 25 mm/mo to lysimeters increased the leaching of Ca and Mg.

Tamm *et al* (1977) installed lysimeters in a sandy soil and applied 4 treatments to them (plus a control, contents unknown): 100 kg H_2SO_4 /ha, 120 kg N/ha, 40 kg P/ha, 76 kg K/ha and combinations of these treatments. Sulphuric acid increased the leaching of the cations.

Wood and Bormann (1977) applied simulated acid rain to a sandy loam soil once a week. Leaching of Mg and Ca steadily increased with "rain" acidity through the pH range 5.6-2.3 K losses did not increase until the "rain" pH was lowered to 3.0 and 2.3. Declines in exchangeable K, Mg and Ca were measured at pH 3.0 and below. Greatly

depleted levels of exchangeable cations were found at pH 2.3.

A lysimeter study plot in a Douglas-fir ecosystem was leached with aliquots of H_2SO_4 ranging in concentrations from 10 to 1000 times higher than natural rainfall (Johnson and Cole, 1977). The data showed that the ecosystem had the ability to buffer and moderate cation losses from heavy loads of H_2SO_4 over short periods.

A mixture of 1:1:1 calcareous soil, sand and manure was irrigated with "rain" of pH 3.1 and 3.5 (H_2SO_4 added to deionized water) and a control (deionized water) (Matziris and Nakos, 1978). 100 mm simulated acid rain was applied monthly for a year. Ca decreased to 17 meq/100 g (pH 3.1) from 18 meq/100 g (control 5.1). Mg and K changed even less.

Roberts et al (1980) set up an experimental field site on a podzol soil in a pine forest in central England. After applications of 25 and 50 kg S/ha/ann. as H_2SO_4 (pH 3.1 and 2.7) for 5 months no effect on the rate of Ca, Mg, Na and K leaching from the soil was observed.

After experimentation with H_2SO_4 and soils Johnson (1980) found that cation leaching from soils due to sulphuric acid inputs cannot occur unless sulphate is mobile in the soil or it displaces another anion that is

mobile in the soil. Singh et al (1980) came to a similar conclusion after watering lysimeters with simulated rain with an ionic composition similar to Norwegian rain having pH 5.65 and 4.3 (H_2SO_4). They found that the effect of the leaching ability of acidic precipitation on the removal of Ca, Mg, Mn and Al was more pronounced in a semi-podzol than in the iron podzol. SO_4 adsorption regulates the cation removal from the soil profile.

15.2.2 Decreases in Soil pH

Based on experimental data, not outlined, Wiklander (1973/74) feels that soil pH should decrease markedly due to acidic precipitation. In 1975 Wiklander leached a podzol with H_2SO_4 (pH 3.56). It was found that the salts in the percolating solution caused a decrease in pH in the leachate.

Malmer (1976) in his review of Scandinavian research is not surprised everyone finds pH decreased in experiments using simulated acid rain. He stresses that the amount of acid used in experiments are usually greater than what are found in nature and the time period of experimentation is shorter.

Abrahamsen et al (1976) found that increasing the acidity (pH 6 to 2.0) of simulated acid rain in field plot experiments reduced the pH of podzol soils. Less podzolized soils were influenced less by acid rain.

After leaching a sandy-loam soil with artificial acid rain for 20 weeks, Wood and Bormann (1977) found marked soil pH declines with pH treatment 2.3.

Matziris and Nakos (1978) found after leaching man-made soils with pH 3.1 and 3.5 (H_2SO_4 and deionized water) that the pH of the original soil-manure mixture of 7.4 did not change.

Rippon (1980) found a tendency toward soil pH reduction after leaching soil with sulphuric acid (pH 3.0).

15.2.3 Mobilization of Soil-Bound Metals

(Al, Fe, Mn, etc.)

In his 1975 experiments Wiklander found that the release of Al and Fe from a podzol was about the same in a series with H_2SO_4 (pH 3.56) and salts as in the series with only salts.

Tamm (1976) in a literature survey found that many experiments had shown that release of Al and heavy metal ions occur with increasing acidity.

Abrahamsen et al (1976) found in their lysimeter studies that in the podzol-brown earth soil net losses were found for Al, along with Ca and Mg. In the podzol lysimeter net losses were additionally found for Fe, Mn and also K and Na.

Dickson (1978) presents findings of a study done by Wiklander in which 100 kg of H_2SO_4 per hectare were added to a lysimeter for 5 years. The concentration of Al in the leachate increased to more than 1 mg/l but was only 0.2 mg/l in the non-treated soil water.

15.2.4 Changes in Soil Microorganisms

Crowther and Ruston (1911-12) added rainwater acidified with H_2SO_4 to a mixed soil. They found that the total number of bacteria diminished rapidly with increasing acidity.

Abrahamsen et al (1976) found in their simulated acid rain experiments that the various acid treatments did not influence the total abundance of enchytraeid. Different species, however, seem to respond differently to the various acid treatments. Results from the podzol experiment (1976) indicated an enchytraeid population increase when the amount of H^+ ions applied increased from 0.5 me to 55 me. Further application decreased the population density. In the podzol-brown earth soil no effect was observed.

Tamm et al (1977), after leaching soils in Sweden with acids and salts, found that an acidification of soil decreases microorganism activity.

Alexander (1980) concluded from experiments with acid, which were not described, that the total bacterial community is reduced with decreasing soil pH as are individual physiological groups. The actinomycetes, which taxonomically are considered to be bacteria, are generally less abundant as pH falls. The relative abundance of fungi rises, an increase that may be associated with the lack of competition from other heterotrophs at the lower soil pH level.

In a continuation of their 1976 research, Abrahamsen et al (1977) found a number of enchytraeids in a podzol increased after acidification with groundwater and sulphuric acid. Mesostigimata tended to be reduced by acidification while Brachychthoniidae appeared to increase.

Rippon (1980) leached 50 soils with distilled water and sulphuric acid (pH 3.0). Preliminary results from the pot studies showed no significant change in bacterial population.

Baath et al (1980) added 50 and 150 kg H_2SO_4 /ha/yr to an iron podzol in Sweden. Preliminary results indicate a decrease in the "active" fungi mycelium in the acidified plots. The bacterial biomass demonstrated similar changes with a more pronounced decrease than fungi. Most of the species of enchytraeids showed no significant change. However, Trachytes and Oppia

obsoleta decreased slightly while the dominant Collembola species increased in the acidified plots.

15.2.5 Decrease in Nitrate and Nitrification

Crowther and Ruston (1911-12) found that increasing soil acidity led to a decrease in the nitrite content.

Hovland and Ishac (1975) of the SNSF group irrigated a semi-podzol with simulated acid rain pH 5.6, 4.0, 3.0 and lime. Samples were analyzed for NH_4 , NO_2 and NO_3 . Nitrifying microorganisms were found in all soils whether limed or not. Nitrification only took place in humus samples from limed plots.

Alexander (1980) found that, generally, nitrifying bacteria are very sensitive to acidity. Their activity level falls rapidly with a decrease in pH and is undetectable below pH 4.5.

15.2.6 Decrease in Soil Respiration

Tamm et al (1977) found from incubation studies on podzol soils that a depression of the release of CO_2 occurred when either H_2SO_4 or powdered S was added to the soil.

Rippon (1980) on the other hand found no significant effects on CO₂ evolution after leaching soil with H₂SO₄ (pH 3.0).

15.2.7 Destruction of Soil Organic Matter

Schnitzer (1980) in experiments with unspecified acid loadings on soil found that the structure of fulvic acid changed at a low pH. Schnitzer noted that he could foresee severe soil degradation under very high inputs of acidic precipitation. A soil pH 2-3 would be necessary to achieve severe leaching of fulvic acid. Humic acid would not be so affected because they are insoluble at low pH's.

15.3 Effects of Acidic Precipitation from a Point-Source on Local Soil

15.3.1 Cation Leaching

Experimental sites were located at varying distances from SO₂ sources in Alberta (Baker et al, 1977). Exchangeable bases were low in soils suspected of SO₂ contamination.

Hutchinson (1980) examined the soils near Smoking Hills in the Canadian Arctic and at Sudbury, Ontario. At Sudbury the soils had low Ca concentrations in the

leachates. Following rains, high concentrations of Ca, Mg and Mn, Fe, Al and Zn were present in runoff and in tundra ponds in the acidified area near Smoking Hills. These elements have apparently been mobilized at low soil pH's.

15.3.2 Decrease in Soil pH

In Alberta in 1972 Nyborg et al (1973) exposed top soil from a Gray Luvisol to S emitted near the Shell water and gas plant for 1 year. Soil pH was determined from 1 to 3 cm depth. A Dark Brown loamy soil was also examined for 4 months only. The pH of the Gray Luvisol was an average of 0.1 pH units lower downwind from the plant compared to those soils not downwind. The Dark Brown soil near the plant had a pH 0.06 units lower than soil farther away from the S source. Results of an expansion of this program in 1977 (Nyborg et al) demonstrated that pH of soil in an area over 1000 km² from the gas plant under closed canopy was depressed at least 0.15 units over 3 months. pH depression in the forested sites is only half as great as that in the prairie sites. The authors conclude that soils are slowly acidified by SO₂ at a rate estimated at 1 pH unit in 10 to 20 years. Further experimentation near SO₂ sources in Alberta by Baker et al (1977) verified that SO₂ appears to be having an acidifying effect on soil solution at sites near major sources.

Hutchinson and Whitby (1977) studied Gray Luvisols near the Sudbury Smelter. They found increased acidity of the soil near the smelter (pH 3.0) and increased metal mobility. Further experimentation in the Sudbury area by Freedman and Hutchinson (1980) concluded there was no discernible distance to smelter related change in soil litter pH, mineral soil pH or base leaching.

15.3.3 Mobilization of Soil-Bound metals
 (Al, Fe, etc,.)

Hutchinson and Whitby (1977) attributed the increased soil metal mobility and solubility near the Sudbury smelter to increased acidity of the soil (Gray Luvisol).

Scheider et al (1979) state that Mn and Al are good indicators of watershed acidification since they are readily removed from the soils by acidic precipitation. Lakes near the Sudbury area have Al concentrations of approximately 50 mg/l with probable background levels closer to 2-10 ug/l. Mn concentration in the lakes are greater than 200 ug/l while 3 ug/l is considered to be the background level.

Hutchinson (1980) found that Mn, Fe, Al and Zn were present in high concentrations in runoff following rains and in tundra pools in the acidified area near Smoking

Hills. He summarizes that mobilization and speciation of metals in the soil appear to be strongly pH dependent. At lower soil pH's the residence times of metals in soil is much shorter relative to higher pH's.

15.3.4 Change in Soil Microorganisms

Soils in Alberta were sampled 1 m and 200 m from elemental S in a stockpile and in a garden plot (Bryant et al, 1979). Significant reduction in bacteria were observed in acidified soils.

In their examination of the soils near the Sudbury smelter Freedman and Hutchinson (1980) found that close to the smelter lower populations of soil microfungi and micro-arthropods occur.

As reported by Linzon (1978), unpublished studies by Balsillie and Bisessar showed that the number of colonies of bacteria, actinomycetes and fungi in soil decreased with proximity to the Sudbury sulphur fume sources.

15.3.5 Decrease in Soil Respiration

In their research on soil around an S stockpile in Alberta, soil respiration (CO₂ evolution) was measured in a static system (Bryant et al, 1979). Soil (pH 6.8) 200 m away from the S block showed reduced soil respiration

when artificially acidified to pH 2.9 but not as drastically as found in the long term pH 3.0 soil. A garden soil (pH 7.7) was acidified to pH 3.2 and showed no reduction in total soil respiration rate. This is probably due to its physical structure and biological composition.

Freedman and Hutchinson (1980) found that close to the Copper Cliff smelter lower rates of soil metabolism were prevalent.

15.4 Changes Found in Soil in Nature Due To Acidic Precipitation

15.4.1 Cation Leaching

Soil weathering studies in the Hubbard Brook Ecosystem demonstrated that cationic denudation of the upland areas of New England does not appear to be unduly accelerated at the present time as a result of acidic precipitation (Johnson et al, 1972).

In a 10 year (1931-1940) lysimeter study in Connecticut Na was leached completely from the soil (Frink and Voight, 1977). Mg also leached readily. Ca was leached in much greater amounts than those added. From 40-50% of the K was fixed in the soil and was not lost by leaching.

Mayer and Ulrich (1977) undertook an element balance investigation in a beech forest in Central Germany. They found that Na, K, Ca and especially Mg were leached from the soil due to natural acidic precipitation.

Jeffries et al (1979) found that cations (Ca and Mg) in the podzolic overburden in Central Ontario were replaced by H^+ .

The chemical characteristics of a small stream, Falls Brook, in the Hubbard Brook Ecosystem were monitored for three years. Neutralization of acid rain is rapidly and largely (75%) accomplished in the upper soil by the leaching of bases (Johnson, 1979).

15.4.2 Decrease in Soil pH

Wiklander (1973/74) resampled an iron-humus podzol in Sweden that had been originally studied in 1934. Soil pH was determined with water, 1M KCl and 0.01 M $CaCl_2$. Wiklander found no significant pH change had taken place in the last few decades. He concludes that increased deposition of S was apparently not sufficient to change stable acid conditions of Swedish podzols as registered by soil pH. Similarly Linzon and Temple (1980) in Ontario found little change in pH in podzolic soils in Ontario after an 18-year period (1960-1978).

In a 10 year lysimeter study (1931-1940) in Connecticut soil, pH decreased from 5.4 to 5.0 (Frink and Voight, 1977).

Cole and Johnson (1977) attempted to monitor the effects of present levels of atmospheric sulphuric acid input on cation leaching in Washington state. A podzolic soil was monitored for pH beneath the litter layer and at the base of the A and B horizons. Data indicated that the precipitation pH frequently fell below 4, but the soil solution never fell below pH 5. Solution pH rose as precipitation passed through the forest canopy and forest floor. Incoming H^+ is absorbed in the forest floor so that no effect of acid rain on soil solution pH is detectable.

15.4.3 Mobilization of Soil-Bound Metals (Al, Fe, etc.,)

From their study of a beech forest in Central Germany, Mayer and Ulrich (1977) found that the accumulation of Fe in the soil is balanced by the loss of Al and Mn.

Dickson (1978) has found by studying Swedish lakes that there is a heavy leaching of Al from the soil in the watersheds under natural conditions.

In a New Hampshire balsam fir forest, water samples were collected from four strata: bulk precipitation, throughflow, forest floor and A₂ horizons by Cronan and Schofield (1979). It was found that H₂SO₄ was prominent in the precipitation and leaching of Al was pronounced in the soil profile. Dissolved Al was in high concentration in the forest floor and continued to increase in concentration with soil depth.

Scheider et al (1979) state that Mn and Al are good indicators of watershed acidification since they are readily removed from soils by acidic precipitation and are naturally low in the precambrian lakes of southern Ontario. Jeffries et al (1979) found that the cations in the podzolic overburden of Central Ontario, which are replaced by H⁺, include Al and to a lesser extent Mn.

Johnson (1979) reports on the three year monitoring of Falls Brook. The chemical data show that the neutralization of acid rain occurs in the upper regolith by the dissolution of pre-existing Al hydroxide compounds.

15.5 Models and Pedological Theories
 on Acid Precipitation and Soils

15.5.1 Cation leaching

According to McFee et al (1977) 100 years of acid precipitation (1000 cm at pH 4.0) could be expected to shift the base saturation in the top 20 cm of a soil with Cation Exchange Capacity of 20 meq/100 g downward 20% if there are no countering inputs of basic materials.

Tamm (1977) explains that the input to the soil from acidic precipitation depends on the soil properties, particularly the amount of exchangeable cations in the soil. On the average, a soil with low base saturation is acid and a soil with high base saturation is neutral or alkaline. Tamm agrees with Wiklander's (1973/74) hypothesis that an input of more H^+ ions to an already acid soil means relatively small change and soils with high base saturation have large buffer capacities.

Norton (1977) outlines the possible results of acidic precipitation on soil, they are:

1. increased mobility of most elements.
2. a general proportionate increase in the rate of removal of all cations from the soil. In initially impoverished or unbuffered soil the removal may be significant in the time scale 10-100 years.

Reuss (1978) presents a model that calculates ion loss from soil as a function of soil properties and of the composition and distribution of rainfall. The initial results indicate that significant acidification and depletion of bases could occur over a period of a few decades if rainfall inputs are consistently acidified to pH 4.0 with sulphuric acid.

Bache (1980) explains that some effects of acidification of soils are loss of base cations and reductions of cation exchange capacity. The exchange of Al^{3+} , for Ca^{2+} and Mg^{2+} , as well as the exchange of H^+ for Ca^{2+} were considered in some detail.

In a discussion of the effect of acidic precipitation on podzolization by increasing the thickness of the eluvial A horizons and further depleting surface soils of the nutrients. Petersen does not expect that it is possible as yet to make direct observations on the effect of precipitation on podzol development.

15.5.2 Decrease in Soil pH

McFee et al (1977) expect that acid precipitation of pH 4.0 could reduce the soil pH of the A horizon by 0.6 units if no countering inputs of basic materials were present.

According to Tamm (1977) if added H_2SO_4 leaves the soils as gaseous H_2S there is no net acidification, however if SO_4 ions are precipitated through the soil, acidification does occur.

15.5.3 Mobilization of Soil-bound Metals (Al, Fe, etc.,)

The output of the model produced by Reuss (1978) confirms that as soil base saturation and lime potential fall to low levels acidic precipitation causes leaching of H^+ and Al^{3+} ions rather than bases. These findings confirm Wiklander's (1973/74, 1980) theory.

15.5.4 Change in Soil Microorganisms

Bache (1980) explains that changes in the soil biological activity are a major effect of acidic precipitation. Alexander (1980) states that nitrifying bacteria are very sensitive to acidity. The total bacterial community is reduced in abundance with lower soil pH's. Fungi, on the other hand, rise in number as soil pH falls. Alexander stresses that short term studies of any stress factor may be misleading because microorganisms may become acclimatized to changes in pH.

15.6 Summary and Conclusions
 Direct Effect on Soils

Pedological theories and models (Wiklander, 1973/74; McFee, 1977; Tamm, 1977; Reuss, 1978; and Bache, 1980) suggest that leaching of cations could occur in the soil over a few decades if the acidity of the rainfall is less than 4 and the soils are slightly impoverished and not strongly buffered. Experiments with simulated acid rain by Overrein (1972), Wiklander (1973/74) Abrahamsen et al (1976), Wood and Bormann (1977) and Tamm et al (1977) confirm these theories. Other researchers, however, have found moderate or no cation leaching when adding simulated acidic rain to soil (Matziris and Nakos, 1978; Johnson and Cole; 1977 and Roberts, 1980). Of course the results depend on the initial pH and buffering capacity of the soil as well as the pH of the simulated rain. Johnson (1980) and Singh et al (1980) have found that cation leaching from soils due to sulphuric acid inputs cannot occur unless SO_4 is mobile in the soil or it displaces another ion that is mobile in the soil. Baker et al (1977) and Hutchinson (1980) found that cation leaching increased due to S pollution in local soils near the source. Johnson (1972) noted no cation leaching at Hubbard Brook under natural conditions. Jeffries et al (1979) found that some cations were leached from the soil in Central Ontario. However, Frink and Voight (1977), and Mayer and Ulrich (1977) claim they found cations were

leached from the soil due to natural acidic precipitation in Connecticut and Germany, respectively. No research on the natural leaching of cations due to acidic precipitation has been reported since 1977.

McFee et al (1977) theorize that acid rain of pH 4.0 could reduce the pH in the topsoil. Tamm (1977) adds if H_2SO_4 leaves the soil as H_2S there will be no soil acidification, however, the soil pH will decrease if SO_4 ions precipitate through the soil. In experiments with simulated acid rain Wiklander (1973/74), Malmer (1976) Abrahamsen et al (1976), Wood and Bormann (1977) and Rippon (1980) all find that the soil pH fell when they added acidic simulated rain to soil. Matziris and Nakos (1978) found no change in the soil pH. Their original soil pH was above 7.5, however Nyborg et al (1973), Nyborg et al (1977), and Baker et al (1977) have detected small decreases in soil pH (less than 1 pH unit) near S blocks in Alberta. Freedman and Hutchinson (1980) could find no discernible distance to smelter related change in soil pH at Sudbury. Wiklander (1973/74) in Sweden, Cole and Johnson (1977) in Washington State and Linzon and Temple (1980) in Ontario could detect little or no change in soil pH due to present levels of atmospheric acidity. Frink and Voight (1977) claim to have detected a slight decrease (5.4-5.0) in the pH in Connecticut soil under natural conditions.

The output of the model produced by Reuss (1978) and the theories put forward by Bache (1980) and Wiklander (1973/74) suggest that soil-bound metals, particularly Al will be leached from the soil as a result of acidification. Research using simulated acid rain by Wiklander (1975), Tamm (1976) Abrahamsen et al (1976) and Dickson (1978) all confirmed this hypothesis. Work near a S point source at Sudbury by Hutchinson and Whitby (1977) and Scheider et al (1979) found that Al and Mn were leached from the soil. Hutchinson (1980) found similar leaching of soil bound metals in the Arctic near the Smoking Hills. Even the research under natural conditions in Germany, Sweden, U.S.A. and Canada by Mayer and Ulrich (1977), Dickson (1978) Cronan and Schofield (1979) and Jeffries et al (1979), respectively, found that the mobility of Al and often Mn and Fe increased due to natural acidic precipitation.

Bache (1980) and Alexander (1980) hypothesized that changes in the soil biological activity could be a major effect of acidic precipitation. Bacteria are reduced in number with lower soil pH's. Crowther and Ruston (1911/12) and Alexander (1980) found that the number of bacteria in the soil decreased when they added simulated acid precipitation to soil columns. Tamm et al (1977) discovered in Sweden that microorganisms activity decreased in artificially acidified soil. Abrahamsen et al (1976) found that various acid treatments did not

effect soil enchytraeids. Different species responded differently to various acid treatments. Bryant et al (1979) found that bacteria near a S stockpile in Alberta had decreased in number. Freedman and Hutchinson (1980) found that the soil microfungi and microarthropods population decreased close to the Sudbury smelter. No one has reported any research on soil microorganisms in nature in regard to their response to natural acidic precipitation.

Based on the research completed to date with simulated acid rain, the findings in nature and pedological theories one might expect that as the natural precipitation acidity reaches pH 4.0 and lower we could expect increased cation leaching in sandy soils that are moderately buffered, along with a decrease in soil pH in Ontario. The acidification of soil will cause Al and other metals such as Mn and Fe to become more soluble and leach into the surrounding waters. Soil bacteria may reduce in number in acidified soils but fungi could increase their activity. Other changes such as reduction in soil respiration, nitrification and loss of clay minerals may occur also with lower precipitation acidity.

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16. CONCLUSION

This submission substantiates Ontario's case before the United States Environmental Protection Agency that the Agency must consider the following points when dealing with interstate pollution abatement:

1. Multiple sources instead of sources on a singular basis.
2. Multiple pollutants or co-pollutants instead of pollutants on a singular basis.
3. Secondary pollutants as well as primary pollutants.

By properly and adequately addressing these points Ontario feels that the necessary first steps to deal with the problem of interstate pollution transport will have been taken.

THE PROVINCE OF ONTARIO

**A Submission to the
United States Environmental Protection Agency
Opposing Relaxation of SO₂ Emission Limits in
State Implementation Plans
and Urging Enforcement**

March 12, 1981

Expanded March 27, 1981



**Ministry
of the
Environment**

**Hon. Keith C. Norton,
Minister**

**Graham W. S. Scott, Q.C.,
Deputy Minister**

EXPANDED MARCH 27, 1981

This submission to the U.S. Environmental Protection Agency is an expanded version of Ontario's March 12, 1981 document which opposes the proposed SIP emissions that would substantially increase SO₂ emissions at 18 power plants in six states and thereby, damage Ontario's environment. This expanded document now also addresses the Matter of Proposed Revisions to the Ohio State Implementation Plan, namely Sulphur Dioxide Emission Limits for the Eastlake and Avon Lake Plants of the Cleveland Electric Illuminating Company, Docket No. 5A-79-1.

Ontario has decided to submit this expanded version, including all 20 plants, rather than make a separate submission concerning the two Cleveland area plants. Such a separate submission would have extensively cross-referenced the earlier document. By integrating the March 12, 1981 data with new information pertinent to the cases, all evidence is hereby presented in a single document.

BEFORE THE
ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

In the Matter of Proposed Revision to the Ohio State Implementation Plan: Ohio Sulphur Dioxide Control Plan (OAC Chapter 3745-18 Sulphur Dioxide Standards); and	:	Docket No. 5A-80-3
In the Matter of Proposed Revision to the Ohio State Implementation Plan: Sulphur Dioxide Emission Limit for the Toledo Edison Bayshore Plant; and	:	Docket No. 5A-75-6
In the Matter of Proposed Revision to the Ohio State Implementation Plan: Sulphur Dioxide Emission Limits for the Eastlake and Avon Lake Plants of the Cleveland Electric Illuminating Company; and	:	Docket No. 5A-79-1
In the Matter of Proposed Revision to the Illinois State Implementation Plan: Sulphur Dioxide Emission Limit for the Illinois Power Company Baldwin Steam Electric Plant; and	:	
In the matter of Proposed Revision to the Indiana State Implementation Plan: Sulphur Dioxide Emission Limits for Major Coal-Fired Electric Plants and Non-Attainment Plan; and	:	
In the Matter of Proposed Revision to the West Virginia State Implementation Plan: Sulphur Dioxide Emission Limit for the Ohio Power Company Kammer Plant; and	:	
In the Matter of Proposed Revision to the Tennessee State Implementation Plan: Sulphur Dioxide Emission Limit for the Tennessee Valley Authority Kingston Plant; and	:	
In the Matter of Proposed Revision to the Michigan State Implementation Plan: Sulphur Dioxide Emission Limit for the Consumers Power Company Cobb Plant; and	:	
In the Matter of Approval of Revision to the Michigan State Implementation Plan: Sulphur Dioxide Emission Limit for the Consumer Power Company J.H. Campbell Plant.	:	

SUBMISSION OF THE PROVINCE OF ONTARIO URGING
DISAPPROVAL OF PROPOSED REVISION OF STATE
IMPLEMENTATION PLANS AND URGING RECONSIDERATION
OF APPROVED REVISIONS AND COMMENTS

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(Expanded: March 27, 1981)

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BEFORE THE
ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

1.

INTRODUCTION

The Province of Ontario urges the Environmental Protection Agency (EPA) to disapprove any proposed revisions to State Implementation Plans in these proceedings which would lead to increases in allowable sulphur dioxide emissions from the power plants which are the subject of these proceedings. Where revisions have been approved by EPA, Ontario urges that these be reconsidered and no revisions be allowed which would lead to increased SO₂ emissions. Ontario also makes comments in these proceedings.

Ontario seeks the results urged by it on the basis of:

- (a) Rights conferred by accords
- (b) Principles of international law; and
- (c) Section 115 of the Clean Air Act.

Ontario says that the power plants subject to these proceedings significantly contribute to acid deposition in Ontario. Current levels of deposition already result in harmful effects on Ontario's lakes and aquatic life as documented in Chapters 5, 6 and 7 and, hence, on the well-being of its residents. Ontario submits that any increase in SO₂ emissions from these sources will further impair the Ontario environment and should not be approved. In addition, other links between SO₂ deposition and damages to terrestrial ecosystems and man-made structures have been identified by researchers in several jurisdictions. Ontario has initiated a program of studies to determine the nature and extent of these effects, although results of these studies are not yet available.

Ontario also urges the EPA to vigorously enforce existing SO₂ emission standards. Our position is based on international legal principles.

No adequate evaluation has been made by EPA in these proceedings of the long range transport of pollutants to enable an assessment of the effect on Ontario of the increases sought. If EPA does not now disapprove the SIP relaxations, it should, prior to making a decision, proceed to carry out an evaluation of the cumulative impact of the revisions on Ontario and other provinces. Further, EPA should include the cumulative impact on Ontario in its evaluation of any other SIP revision it may be called on to consider. Ontario submits that this can only be accomplished by consolidation of proceedings.

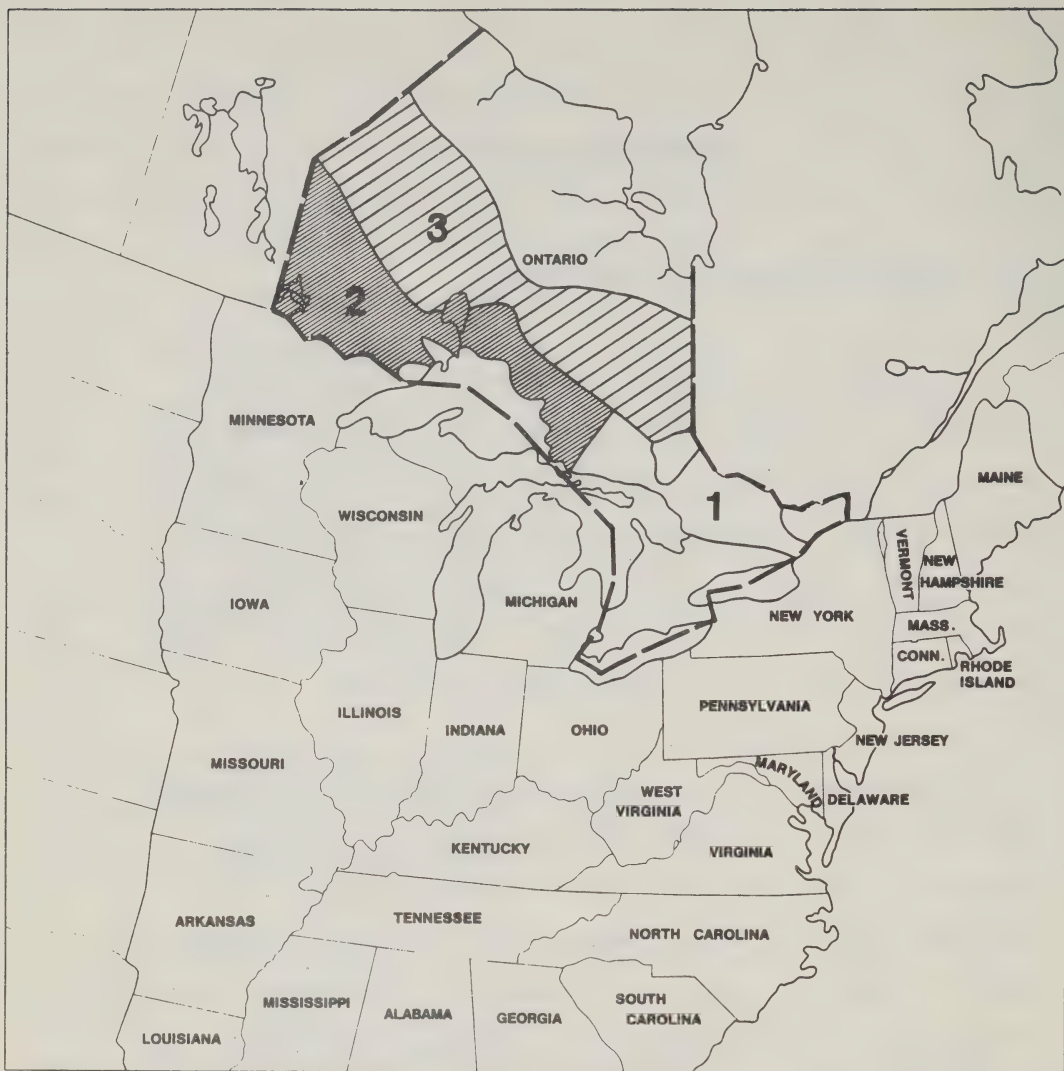
BACKGROUND INFORMATION

2.1 Ontario's People and Environment

The province of Ontario is Canada's second largest province. It covers 344,092 square miles, stretching from the Great Lakes and the St. Lawrence River to the shores of Hudson's Bay. It has approximately 35% of Canada's total population; that is, 8.5 million people concentrated primarily in the urban centres of the south. The location of Ontario relative to the U.S. is illustrated in Map 2.1.

Ontario has a vital, thriving and diversified economy, much of which is dependent upon the province's natural resources. Parts of this resource base are known to be adversely affected by acid deposition. The deterioration or loss of these resources will undermine a significant proportion of Ontario's regional economies, and cause the loss of jobs and incomes.

The aquatic based tourism and outdoor recreation sectors are significant to Ontario's economy, accounting for nearly 10% of the province's economic base. These activities



Map 2.1 The Province of Ontario, shown relative to the Eastern part of the U. S. The shaded areas approximate environmentally sensitive terrain with lakes susceptible to precipitation acidity. The bulk of this terrain lies on the geological formation known as the Canadian Shield.

Code	Total No. of Lakes	Estimated Percentage Sensitive	No. of Lakes Sensitive Based on Estimate
1	40,589	50 %	20,295
2	76,728	20 %	15,346
3	64,133	20 %	12,827
TOTALS	181,450		48,468

generate direct expenditures, conservatively estimated at \$900 million in 1980. The importance of these sectors is even greater when indirect expenditures are taken into consideration, and when their net present value is calculated over the period to 2001.

In the sensitive shield area of the province (see Map 2.1), tourism and recreation account for up to 20% of some regional economies. This percentage is all the more significant due to the seasonal nature of the activities. The present and potential extent of biological damage to lakes and rivers supportive to these activities has not been fully defined, but on the basis of the latest data, indications are that 20% to 50% (36,300 to 90,750) of the lakes in these important recreational areas are sensitive to the effects of acid deposition.

The Muskoka-Haliburton area (Code 1, Map 2.1) is a prime recreation area for both Ontario residents and tourists. This area is particularly sensitive to acid deposition and currently receives a heavy acid loading from the atmosphere. This region is adjacent to the highly urbanized areas to the south. Its lakes, rivers and wilderness serve as the base of a very large tourism and recreation sector. The more remote northern areas are even more important as tourist vacation areas.

In summary, much of Ontario's economy is dependent on the province's rich natural resource base. The lakes and wilderness are a large but threatened resource, as the documented evidence in Chapter 6 on aquatic ecosystem effects indicates. The province has nearly half a million lakes, of which some 180,000 are located in the geological areas most sensitive to the effects of acid deposition. These physically sensitive areas lack the natural ability to neutralize acid deposited from the atmosphere.

Our research has developed strong linkages between acid deposition and its effects on the aquatic resource base, and between this base and the magnitude and economic value of the tourism and outdoor recreation sectors. The relationships in other areas such as terrestrial systems are less well documented but preliminary evidence suggests that acid deposition has detrimental effects on these resources which will adversely affect the provincial economy.

2.2 Sources Subject To These Proceedings

A total of twenty fossil fuel-fired thermal generating stations in six states are the subject of these proceedings. They vary considerably in terms of size, load factor, sulphur content of fuel and SIP sulphur dioxide limits. These data for each plant are summarized in Table 2.1 while Map 2.2 shows their locations.

Together, these plants account for about 19,700 megawatts (MW) of electrical power generating capacity, approximately 19% of the region's total capacity. The proportion of capacity which these plants represent varies from state to state from about 5% to 37%, as shown in Table 2.2.

Utilities throughout the United States are a large and significant contribution to total sulphur dioxide emissions. Data for 1978 and 1979 summarized in Table 2.3 indicate that utilities account for 67% to 92% of the total state emissions for the six states in which the 20 power plants are located.

The sulphur dioxide emissions from these states total approximately nine million metric tons (i.e. tonnes), or roughly 40% of the U.S. total SO₂ emissions. All utilities in these six states contribute 7.2 million metric tons to this total. This represents about 78% of the region's total sulphur dioxide emissions which is considerably higher than the national average.

TABLE 2.1

STATE	PLANT NAME	COMPANY NAME	COUNTY	GENERATION CAPACITY MW	AVE % IN SULPHUR COAL BY WEIGHT	LOAD** FACTOR %	PRESENT SIP LIMIT (LBS SO ₂ /MILLION BTU
ILLINOIS	Baldwin	Illinois Power Co.	Randolph	1892	2.90	66.79	4.62
	Clifty Creek	Indiana & Kentucky Elec. Corp.	Jefferson	1304	3.95	76.31	1.20
	Tanners Creek	Indiana & Michigan Electric	Dearborn	1098	2.37	49.65	1.20
	Michigan City	Northern Indiana Public Service	La Porte	736	2.49	46.42	1.20
	Culley	Southern Indiana Gas & Electric	Warrick	414	3.34	58.94	1.20
	Bailly	Northern Indiana Public Service	Porter	615	3.09	41.92	1.27
	Stout	Indianapolis Power & Light	Marion	935	1.73	38.89	1.20
	Warrick	Southern Indiana Gas & Electric	Warrick	323	3.24	25.01	1.20
	Mitchell	Northern Indiana Public Service	Lake	529	1.00	49.19	1.20
	Cobb Campbell	Consumers Power Consumers Power	Muskegon Ottawa	510 650	2.58 2.18	73.24 61.09	1.00 ⁺ 1.50 ⁺
MICHIGAN	Beckjard	Cincinnati Gas & Electric	Clemont	1416*	2.35	41.38	5.62
OHIO	Muskingum Cardinal	Ohio Power Co. Buckeye Power Inc. & Ohio Power Co.	Morgan Jefferson	1530* 1880*	5.19 1.81	61.19 64.14	6.48 4.76
	Bayshore Poston	Toledo Edison Columbus & Southern Ohio	Lucas Athens	655* 240*	0.94 3.92	68.83 34.81	1.20 3.94
	Avon Lake	Cleveland Electric Illum.Co.	Lorain	1307*	2.58	44.27	1.15 ^{***}
	Eastlake	Cleveland Electric Illum.Co.	Lake	1289*	3.26	52.54	1.43 ^{***}

...continued/

TABLE 2.1 (continued)

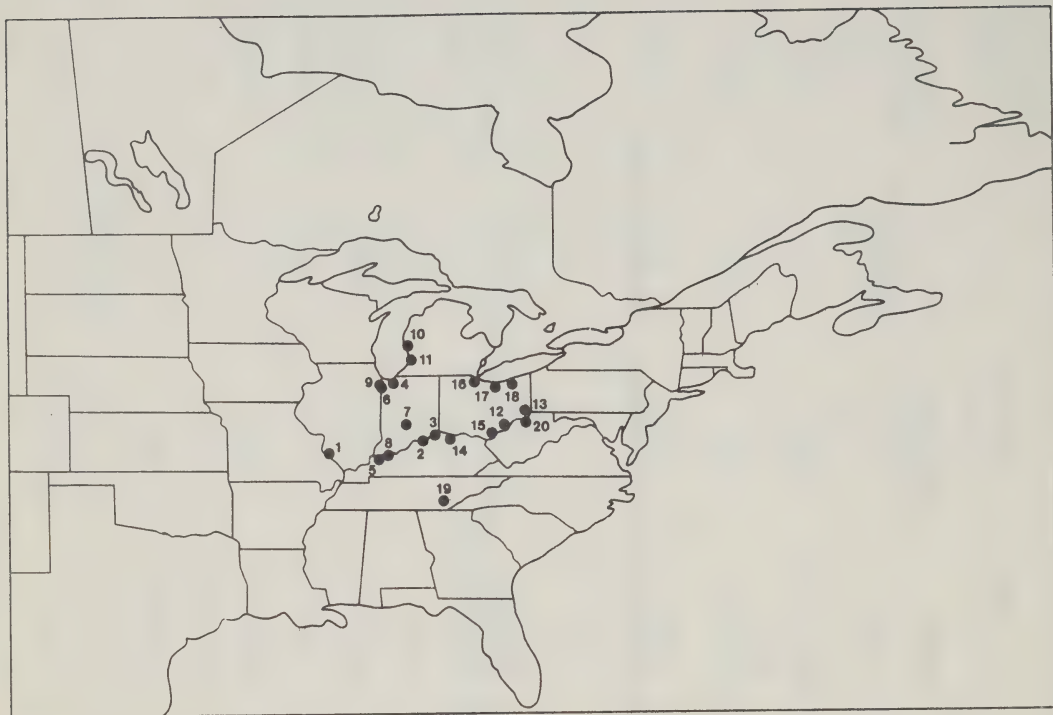
STATE	PLANT NAME	COMPANY NAME	COUNTY	GENERATION CAPACITY MW	AVE % IN SULPHUR COAL BY WEIGHT	LOAD** FACTOR %	PRESENT SIP LIMIT (LBS SO ₂ /MILLION BTU)
TENNESSEE	Kingston	Tennessee Valley Authority	Roane	1700	1.27	61.10	1.20
WEST VIRGINIA	Kammer	Ohio Power	Marshall	675	4.31	72.98	3.20

* c.f. EPC, Form 4 "Monthly Power Plant Report" (F.E.R.C. Form No. 4), January - December, 1979.

+ Per cent sulphur by weight

** as calculated on the basis of fuel consumption

*** We use August 27, 1976 SIP emission limits for the Avon Lake and Eastlake Plants (i.e. 1.15 and 1.43 lbs. SO₂/MBTU respectively) as the base and oppose any relaxation thereof.



Map 2.2 Location of the sources which are the subject of these proceedings.

ILLINOIS

- 1) Baldwin

MICHIGAN

- 10) Cobb
- 11) Campbell

TENNESSEE

- 19) Kingston

INDIANA

- 2) Clifty Creek
- 3) Tanners Creek
- 4) Michigan City
- 5) Culley
- 6) Bailly
- 7) Stout, Elmer W.
- 8) Warrick
- 9) Mitchell, Dean H.

OHIO

- 12) Muskingum
- 13) Cardinal
- 14) Beckjord
- 15) Poston
- 16) Bayshore
- 17) Avon Lake
- 18) Eastlake

WEST VIRGINIA

- 20) Kammer

TABLE 2.2

Thermal Power Generation

<u>State</u>	<u>Total State Capacity (MW)</u>	<u>Map 2.2 Power Plants' Total Capacity by State (MW)</u>	<u>As % of State's Capacity</u>
Illinois	23,470	1,892	8.06
Indiana	16,116	5,954	36.04
Michigan	15,606	1,160	7.4
Ohio	26,145	8,317	31.81
Tennessee	13,086	1,700	14.07
West Virginia	12,500	675	5.4
Regional Total	<u>106,923</u>	<u>19,698</u>	<u>18.42</u>

Source: Inventory of Power Plants, U.S.
Department of Energy, April 1979.

TABLE 2.3

SO₂ EMISSION BY STATE IN 1978 and 1979*

	Total State Emissions, 1978 (thousands of metric tons)	1979, All Utility Emissions (thousands of metric tons)	Utilities As a % of State's Total
	<hr/>	<hr/>	<hr/>
Illinois	1,585.0	1,082.5	68.3
Indiana	1,676.7	1,399.3	83.5
Michigan	1,014.1	676.3	66.7
Ohio	2,826.2	2,302.4	81.5
Tennessee	1,054.9	814.9	77.2
W. Virginia	952.1	875.3	91.9
	<hr/>	<hr/>	<hr/>
REGIONAL TOTAL	<u>9,109.0</u>	<u>7,150.7</u>	<u>78.5</u>

* 1979 total State emission data not available;
1978 emissions are assumed to be sufficiently
similar to 1979 for this purpose.

Many of the power generating plants which are the subject of these proceedings are located in or near large urban areas in the U.S. midwest, and the plants service their regional residents and industries. The cities of Cleveland, Gary, Cincinnati, Evansville, Toledo, Indianapolis and Grand Rapids are the centres of major manufacturing industries, primarily metals related: iron, steel, aluminum, and machinery and automobile parts. This area is a very heavily industrialized and populated region of the United States. As an example of activity in the vicinity of each power plant, Table 2.4 presents some information for those counties in which the 20 generating stations are located, and indicates the magnitude of the manufacturing sector. The data on value of industrial shipments indicates the economic importance of metals processing (iron, steel and non-ferrous metals); automobile parts manufacture (engines, bodies, carburetors); and machinery (farm, valves, pumps, and petroleum refining).

It is recognized that these industries constitute a significant part of the economic base of both this region as well as other parts of the United States. These industries are generally large consumers of electrical power, generated in part by the 20 power plants which are the subject of these proceedings.

TABLE 2.4*

STATE	PLANT	COUNTY	1977 POPULATION	URBAN CENTER (in or near)	NO. OF MANUFACTURING PLANTS IN COUNTY WITH EMPLOYEES SIZE OF:			INDUSTRIAL SHIPMENTS \$ Million	MAIN INDUSTRIES & VALUE OF SHIPMENTS \$ 1979 Millions
					20 TO 100	OVER 100			
ILLINOIS	BALDWIN	RANDOLPH	34,143	-	11	3	196		Printing (61)
	CLIFTY CREEK	JEFFERSON	28,532	-	20	10	244		Motors & Generators (70)
INDIANA	TANNERS CREEK	DEARBORN	33,622	CINCINNATI	13	7	455		Liquor (365)
	MICHIGAN CITY	LA PORTE	108,151	MICHIGAN CITY	97	45	1,116		Farm machinery (186)
	CULLEY	WARRICK	38,985	EVANSVILLE	12	3	491		Compressors (68)
	BAILLY	PORTER	107,816	GARY	38	8	2,716		Primary Aluminum (447)
	STOUT	MARION	774,484	INDIANAPOLIS	575	190	8,457		Steel Mills (2427)
	WARRICK	WARRICK	33,622	EVANSVILLE	38	8	491		Engines (941) Auto Parts (327)
MICHIGAN	COBB	MUSKEGON	159,662	MUSKEGON	137	39	1,514		Pharmaceuticals (595) Aluminum (447)
	MITCHELL	LAKE	556,290	GARY	192	86	7,052		Steel Mills (2110) Petroleum (1812) Non-Ferrous Metals (413)
	CAMPBELL	OTTAWA	150,459	GRAND RAPIDS	N/A**	N/A**	1,360		Autoparts (175) Non-ferrous foundries (126) Paper Mills (121) Autoparts (88) Metal Stamping (48)

.. continued/

TABLE 2.4* (continued)

STATE	PLANT	COUNTY	1977 POPULATION	NO. OF MANUFACTURING PLANTS IN COUNTY WITH EMPLOYEES SIZE OF:			INDUSTRIAL SHIPMENTS \$ Million	MAIN INDUSTRIES & VALUE OF SHIPMENTS \$ 1979 Millions
				URBAN CENTER (in or near)	20 TO 100	OVER 100		
OHIO	BECKJORD	CLERMONT	119,982	CINCINNATI	32	10	185	Specialty Machinery (86)
	MUSKINGUM	MORGAN	13,935	-	6	3	126	-
	CARDINAL	JEFFERSON	95,258	-	39	18	1,072	Steel Mills (750)
	BAYSHORE	LUCAS	476,619	TOLEDO	408	130	6,463	Petroleum (1663)
	POSTON	ATHENS	48,888	-	17	4	63	Cars & Parts (1557)
	AVON LAKE	CORAIN	264,000	LORAIN-ELORIA	170	65	5,342	Hosiery (33)
TENNESSEE	EASTLAKE	LAKE	211,000	CLEVELAND	227	54	1,905	Motor Vehicles and Car Bodies (2407)
	KINGSTON	ROANE	42,916	-	19	7	172	Blast Furnaces, Steel Mills (1261) Organic Chemicals (536)
WEST VIRGINIA	KAWWER	MARSHALL	40,590	WHEELING	15	6	355	Trucks and Tractors (134)
								Ind. Process Control Inst. (118)
								Games & Toys (62)

*Information Sources: - Statistical Abstract of the U.S., 1976

- Sales and Marketing Management, April 1980, Vol 124, No. 6

**N/A means "not available"

However, the need to protect Ontario's environment and the environment of several northeastern states is urgent, as we will show in Chapters 5 through 7. A ranking of Ontario's coal-fired plants and U.S. plants in the eastern states, which are the largest emitters of SO_2 (see Table 2.5), and a ranking of the "cleanliness" of eastern U.S. and Ontario plants in terms of pounds of SO_2 emitted per million BTU (see Table 2.6) shows that several of the 20 plants in these proceedings are already in the rankings, for example, the Muskingum, Ohio plant, the Clifty Creek, Indiana plant, the Baldwin, Illinois plant, the Eastlake, Ohio plant, the Kammer, West Virginia plant, the Beckjord, Ohio plant and the Avon Lake, Ohio plant. Furthermore, if the proposed relaxations occur, several of the above plants would then move up in the rankings and some plants not currently in the emitted SO_2 tonnage rankings would then be included, for example, the Tanners Creek, Indiana plant, the Kingston, Tennessee plant, the Warrick, Indiana plant, and the Michigan City, Indiana plant.

While these examples illustrate the larger increases proposed, it is the position of the Ontario Government that it opposes the relaxation of any existing laws, standards, or regulations. The Ontario Government also opposes any failure to enforce existing laws, standards, or regulations which result in increased SO_2 emissions. All emissions of SO_2 produce a cumulative and damaging effect to the environment encompassed by the regional airshed which Ontario, the midwest, and the northeastern states all share.

TABLE 2.5

TOP 50 COAL-FIRED POWER PLANTS RANKED ACCORDING TO TOTAL SO₂

EMISSION IN 1979

RANK	PLANT	STATE	COUNTRY	ESTIMATED SO ₂ EMISSION THOUSANDS OF METRIC TONS/YEAR
1	PARADISE	KENTUCKY	U.S.A.	372.5
2	MUSKINGUM	OHIO	U.S.A.	340.2
3	GAVIN	OHIO	U.S.A.	339.5
4	CUMBERLAND	TENNESSEE	U.S.A.	289.7
5	MONROE	MICHIGAN	U.S.A.	264.9
6	CLIFTY CREEK	INDIANA	U.S.A.	263.7
7	GIBSON	INDIANA	U.S.A.	261.1
8	BALDWIN	ILLINOIS	U.S.A.	257.9
9	LABADIE	MISSOURI	U.S.A.	224.0
10	KYGER CREEK	OHIO	U.S.A.	205.5
11	BOWEN	GEORGIA	U.S.A.	202.6
12	CONESVILLE	OHIO	U.S.A.	186.8
13	MITCHELL	WEST VIRGINIA	U.S.A.	186.2
14	HATFIELDS	PENNSYLVANIA	U.S.A.	167.3
15	NEW MADRID	MISSOURI	U.S.A.	164.0
16	SAMMIS	OHIO	U.S.A.	160.7
17	LAMBTON	ONTARIO	CANADA	160.2
18	WANSLEY	GEORGIA	U.S.A.	159.7
19	HOMER CITY	PENNSYLVANIA	U.S.A.	159.1
20	JOHNSONVILLE	TENNESSEE	U.S.A.	157.9
21	NANTICOKE	ONTARIO	CANADA	155.0
22	GASTON EC	ALABAMA	U.S.A.	154.8
23	MONTROSE	MISSOURI	U.S.A.	147.1
24	HARRISON	WEST VIRGINIA	U.S.A.	142.8
25	BRUNNER ISL.	PENNSYLVANIA	U.S.A.	142.0
26	COFFEEN	ILLINOIS	U.S.A.	141.8
27	CARDINAL	OHIO	U.S.A.	140.8
28	EASTLAKE	OHIO	U.S.A.	137.4
29	KAMMER	WEST VIRGINIA	U.S.A.	136.8
30	KINCAID	ILLINOIS	U.S.A.	136.3
31	KEYSTONE	PENNSYLVANIA	U.S.A.	127.2
32	STUART J.M.	OHIO	U.S.A.	125.6
33	CAYUGA	INDIANA	U.S.A.	121.7
34	SHAWNEE	KENTUCKY	U.S.A.	111.0
35	GALLATIN	TENNESSEE	U.S.A.	110.6
36	MONTOUR	PENNSYLVANIA	U.S.A.	109.4
37	BIG BEND	FLORIDA	U.S.A.	109.2
38	CONEMAUGH	PENNSYLVANIA	U.S.A.	108.9
39	WIDOWS CREEK	ALABAMA	U.S.A.	106.0
40	AMOS	WEST VIRGINIA	U.S.A.	105.2
41	THOMAS HILL	MISSOURI	U.S.A.	104.9
42	JOPPA STEAM	ILLINOIS	U.S.A.	104.9
43	MT. STORM	WEST VIRGINIA	U.S.A.	102.5
44	PETERSBURG	INDIANA	U.S.A.	100.7
45	BECKJORD	OHIO	U.S.A.	99.7

-- TANNERS CREEK

-- KINGSTON

-- WARRICK

-- MICHIGAN CITY

TABLE 2.5 (continued)

TOP 50 COAL-FIRED POWER PLANTS RANKED ACCORDING TO TOTAL SO₂EMISSION IN 1979

RANK	PLANT	STATE	COUNTRY	ESTIMATED SO ₂ EMISSION
				THOUSANDS OF METRIC TONS/YEAR
46	AVON LAKE	OHIO	U.S.A.	98.0
47	FORT MARTIN	WEST VIRGINIA	U.S.A.	94.6
48	MIAMI FORT	OHIO	U.S.A.	94.2
49	LAKEVIEW	ONTARIO	CANADA	91.4
50	YATES	GEORGIA	U.S.A.	88.8

POWER PLANTS WERE CONSIDERED FROM ONTARIO AND 32 EASTERN U.S. STATES.
 THE STATISTICS ARE FROM ONTARIO HYDRO AND THE U.S. DEPARTMENT OF ENERGY;
 THE ANALYSIS WAS PERFORMED BY THE ONTARIO MINISTRY OF ENVIRONMENT, AIR
 RESOURCES BRANCH.

TABLE 2.6

TOP 50 COAL-FIRED POWER PLANTS RANKED ACCORDING TO SO₂ EMISSION"CLEANLINESS" IN 1979

RANK	PLANT	STATE	COUNTRY	ESTIMATED LBS. SO ₂ / MILLION BTU	MAXIMUM ACCORDING TO STATE REGULATION (LBS. SO ₂ / MILLION BTU)
1	MONTROSE	MISSOURI	U.S.A.	10.86	16.00
2	MUSKINGUM	OHIO	U.S.A.	8.72	6.48
3	THOMAS HILL	MISSOURI	U.S.A.	7.85	16.00
4	KAMMER	WEST VIRGINIA	U.S.A.	7.24	3.20
5	PARADISE	KENTUCKY	U.S.A.	7.22	5.20
6	KINCAID	ILLINOIS	U.S.A.	6.94	6.00
7	CLIFTY CREEK	INDIANA	U.S.A.	6.85	1.20
8	COFFEEN	ILLINOIS	U.S.A.	6.78	6.00
9	KYGER CREEK	OHIO	U.S.A.	6.50	8.20
10	NEW MADRID	MISSOURI	U.S.A.	5.75	16.00
11	CUMBERLAND	TENNESSEE	U.S.A.	5.71	5.00
12	MITCHELL	WEST VIRGINIA	U.S.A.	5.39	3.12
13	JOHNSONVILLE	TENNESSEE	U.S.A.	5.15	1.20
14	EASTLAKE	OHIO	U.S.A.	5.14	1.43
15	CONESVILLE	OHIO	U.S.A.	5.11	5.66
16	GIBSON	INDIANA	U.S.A.	5.09	16.00
17	BALDWIN	ILLINOIS	U.S.A.	5.08	1.80
18	GAVIN	OHIO	U.S.A.	4.92	9.50
19	CAYUGA	INDIANA	U.S.A.	4.41	16.00
20	GALLATIN	TENNESSEE	U.S.A.	4.38	5.00
21	BIG BEND	FLORIDA	U.S.A.	4.26	1.50
22	AVON LAKE	OHIO	U.S.A.	4.07	1.15
23	BECKJORD	OHIO	U.S.A.	4.01	2.02
24	LABADIE	MISSOURI	U.S.A.	3.99	16.00
25	HARRISON	WEST VIRGINIA	U.S.A.	3.93	4.11
26	HATFIELDS	PENNSYLVANIA	U.S.A.	3.86	4.00
27	MONROE	MICHIGAN	U.S.A.	3.77	5.60
28	CONEMAUGH	PENNSYLVANIA	U.S.A.	3.77	4.00
29	SAMMIS	OHIO	U.S.A.	3.70	2.91
30	LAMBTON	ONTARIO	CANADA	3.55	-
31	PETERSBURGH	INDIANA	U.S.A.	3.44	16.00
32	JOPPA STEAM	ILLINOIS	U.S.A.	3.41	6.00
33	BRUNNER ISL.	PENNSYLVANIA	U.S.A.	3.38	4.00
34	SHAWNEE	KENTUCKY	U.S.A.	3.37	1.20
35	MIAMI FORT	OHIO	U.S.A.	3.34	3.30
36	LAKEVIEW	ONTARIO	CANADA	3.33	-
37	NANTICOKE	ONTARIO	CANADA	3.29	-
38	WANSLEY	GEORGIA	U.S.A.	3.25	N/A
39	BOWEN	GEORGIA	U.S.A.	3.10	N/A
40	MT STORM	WEST VIRGINIA	U.S.A.	3.09	2.90

...continued/

TABLE 2.6 (continued)

TOP 50 COAL-FIRED POWER PLANTS RANKED ACCORDING TO SO₂ EMISSION
"CLEANLINESS" IN 1979

RANK	PLANT	STATE	COUNTRY	ESTIMATED LBS. SO ₂ / MILLION BTU	MAXIMUM ACCORDING
					TO STATE REGULATION (LBS. SO ₂ / MILLION BTU)
41	HOMER CITY	PENNSYLVANIA	U.S.A.	3.09	4.00
42	CARDINAL	OHIO	U.S.A.	3.00	4.76
43	GASTON EC	ALABAMA	U.S.A.	2.95	1.20
44	YATES	GEORGIA	U.S.A.	2.93	N/A
45	WIDOWS CREEK	ALABAMA	U.S.A.	2.88	1.20
46	FORT MARTIN	WEST VIRGINIA	U.S.A.	2.83	3.20
47	KEYSTONE	PENNSYLVANIA	U.S.A.	2.82	4.00
48	MONTOUR	PENNSYLVANIA	U.S.A.	2.51	4.00
49	STUART J.M.	OHIO	U.S.A.	2.04	3.16
50	AMOS	WEST VIRGINIA	U.S.A.	1.30	2.01

POWER PLANTS WERE CONSIDERED FROM ONTARIO AND 32 EASTERN U.S. STATES.
 THE STATISTICS ARE FROM ONTARIO HYDRO AND THE U.S. DEPARTMENT OF ENERGY;
 THE ANALYSIS WAS PERFORMED BY THE ONTARIO MINISTRY OF ENVIRONMENT, AIR
 RESOURCES BRANCH.

ONTARIO SHOULD BE HEARD IN THESE PROCEEDINGS

As will be evident from the information set out in this submission, Ontario will be adversely affected by any decision of the Administrator which has the effect of increasing allowable SO₂ emissions. Ontario bases its claim to be heard on:

- (a) The Administrative Procedure Act,
- (b) U.S. judicial decisions,
- (c) Section 115 of the Clean Air Act and,
- (d) International law.

The petitions by New York were submitted pursuant to S. 126 of the Clean Air Act. Ontario does not rely on S. 126 as the right to petition conferred under that provision is limited to "any State or political subdivision" and does not include Ontario.

3.1 The Administrative Procedure Act (A.P.A.)

S. 4(d) of the Administrative Procedure Act (A.P.A.) confers a right on an interested person to petition for the issuance, amendment or repeal of a rule. ((5 U.S.C.S.553(e))).

Ontario complies with the requirements of the A.P.A. by submitting the instant submission and comments. Further, 5 U.S.C.S.555(b) provides, in part,

"So far as the orderly conduct of public business permits, an interested person may appear before an agency or its responsible employees for the presentation, adjustment, or determination of an issue, request, or controversy in a proceeding, whether interlocutory, summary, or otherwise, or in connection with an agency function."

As Ontario will be adversely affected by any decision which involves a relaxation of a SIP with respect to SO₂ emissions, we submit that Ontario should, therefore, be heard in these proceedings.

It has been held that approval of a SIP without permitting participation by interested persons was a violation of the A.P.A.

Buckeye Power Inc. v E.P.A., 481 F2d 162
(6th Cir. 1973)

In the Buckeye Power case three power companies protested that the Ohio and Kentucky SIPs were approved by the Administrator without permitting them to participate by notice and comment. Because the Administrator built no record, took no comments from interested parties and permitted no public participation in approving these plans, he violated S.553 of the A.P.A. Thereupon the court vacated the defective approval and

remanded the case to the Agency for compliance. Since the requirements for approval of a SIP revision under S.110(a)(3) of the Clean Air Act are the same as for approval of an initial plan ((S110(a)(2))), the Administrator must allow Ontario to participate in these proceedings.

3.2 Decisions of U.S. Courts

Further support for Ontario's claim to be heard in these proceedings may be found in opinions rendered by American federal appellate courts which permitted access by foreign parties to proceedings before U.S. administrative tribunals.

Cia Mexicana de Gas, S.A. v. Federal Power Commission (Reynosa Pipe Line Co., Intervener), State of Texas et al. v. Federal Power Commission, 167 F.2d 804 (5th Cir. 1948)

Juarez Gas Company, S.A., Petitioner v. Federal Power Commission, Respondent, Southern Union Gas Company, Del Norte Natural Gas Company, Interveners, 375 F.2d 595 (D.C. Cir. 1967)

Both of these cases involve petitions by Mexican corporations seeking to review orders of the U.S. Federal Power Commission. The Mexican companies asserted that the granting of a certificate authorizing the export of natural gas to Mexico affected them as a competitor of the company to whom the certificate was granted. In each case, the Circuit Court of Appeals found that the Mexican companies were "aggrieved parties" within the meaning of the Natural

Gas Act and proceeded to review the orders of the Federal Power Commission. The courts approached the issue on the basis of whether the petitioner was "aggrieved" and thus entitled to participate in the proceedings. The test was whether the Mexican company might be adversely affected by the administrative procedure in question.

Additional support for Ontario's position may be found in the judgement of the United States Court of Appeals in The Wilderness Society et al. (David Anderson and The Canadian Wildlife Federation), Appellants, v. Rogers C.B. Morton, Secretary of the Interior et al.¹ The case concerned the application of a Canadian citizen and a Canadian environmental organization to intervene in litigation aimed at testing whether the Secretary of the Interior had complied with the procedures of the National Environmental Policy Act prior to deciding whether to issue a permit for the trans-Alaska pipeline. The court found that the position of the Canadian environmental organization was sufficiently antagonistic to the positions of U.S. environmental organizations, which were also parties to the litigation, to require the granting of the application for leave to intervene. The word antagonistic was used in the sense of division of opinion concerning possible alternatives. In this case, that division of opinion may lead to the interests of the Province of Ontario going unrepresented unless it is permitted to participate.

3.3 Proceedings Under Section 115, Clean Air Act

Ontario should also be heard in respect of the proceedings under S.115 of the Clean Air Act. The matter under S.115 should in turn be regarded as inseparable from the instant proceedings. It makes little sense to approve SO₂ relaxations now which may conflict with the result of a S.115 proceeding already initiated. The section has been activated in that the two conditions, which must be met before the Administrator is required to give notification to the States where emissions originate, have been complied with. On January 16, 1981, the Administrator said:

"In summary, my conclusions are adequate to warrant the initiation of Section 115. Under this provision, formal notification is given to a Governor that his State must identify and propose pollution control measures to address the international problem, and provide opportunity for public hearing on these plans. I have instructed my staff to examine this issue and recommend which States should be notified."

The activation of S.115 places the Administrator under a legal obligation to give formal notification to the Governors of the States in which emissions originate. Information made available by Ontario in this submission will assist in this determination. Ontario seeks to participate in these proceedings both as a Province being severely affected by acid precipitation and as being in possession of information (regarding effects in Ontario and the causes thereof) which is needed by the Administrator to carry out the obligation which is placed upon him by S.115 of the Clean Air Act.

These proceedings should be combined as otherwise relaxations granted now may be totally inconsistent with results of the ongoing S.115 proceedings and may compromise those proceedings.

3.4 Access Under International Law

Ontario also submits that general principles of international law require it to be heard in this proceeding. The principle of international law relied on below, that every State has a duty of care to prevent its nationals from committing air pollution injury against other States, should be implemented by the recognition of procedural requirements. Among these should be recognition of the principle of the right of access by foreign parties, including both government agencies and individuals, to administrative proceedings which may directly impact on them. Only in this way can the principles of international law discussed more fully below be implemented. Consistent with this, both the States of California and Alaska were allowed to intervene before the National Energy Board of Canada in hearings respecting a natural gas pipeline (Hearing RH-2-79). Such access is implied in accords such as the Great Lakes Water Quality Agreement of 1978 (Articles II and III).

3.5 Stage of the Proceedings*

Ontario should be hear notwithstanding the advanced stage of the proceedings. Ontario learned of these proceedings only after filing of petitions by New York. Only then in late January, 1981 did Ontario become aware of the large number of emission limit revisions under consideration. Yet under the Memorandum of Intent between the U.S. and Canada, signed on August 5, 1980, both governments undertook to "continue and expand their longstanding practice of advance notification and consultation on proposed actions involving a significant risk or potential risk of causing or increasing transboundary air pollution."

Ontario is not aware of the results of any study by E.P.A. or any other U.S. government agency which evaluated whether the cumulative effect of proposed SIP revisions would increase transboundary air pollution nor of any notice given in respect thereof.

*This subsection is redundant with respect to Docket No. 5A-79-1 in view of EPA reopening the comment period.

REFERENCES - CHAPTER 3

1. 463 F. 2d (1972).
2. "ENVIRONMENTAL NEWS"
January 16, 1981.

LAW

4.1 Rights Conferred by Accords

On August 5, 1980 the Government of Canada and the Government of the United States of America entered into a Memorandum of Intent concerning transboundary air pollution. In this document the parties declared their intention

"to develop a bilateral agreement which will reflect and further the development of effective domestic control programs and other measures to combat transboundary air pollution".

Both parties undertook to take certain interim actions pending conclusion of such an agreement. These interim actions included the following undertaking with respect to control measures.

"To combat transboundary air pollution both Governments shall:

- (a) *develop domestic air pollution control policies and strategies, and as necessary and appropriate, seek legislative or other support to give effect to them;*
- (b) *Promote vigorous enforcement of existing laws and regulations as they require limitation of emissions from new, substantially modified and existing facilities in a way which is responsive to the problems of transboundary air pollution; and*

- (c) *share information and consult on actions being taken pursuant to (a) and (b) above".*

It is the position of Ontario that the Administrator must take account of the above undertakings and should make his decision with respect to proposed SIP revisions in a manner consistent with such undertakings. The Administrator signed the Memorandum of Intent and is obviously the person intended to implement those aspects which relate to his functions. Ontario submits that the development of "domestic air pollution control policies and strategies" requires the Administrator to take account of the impact on Ontario and other Provinces of emissions originating in States seeking SIP revisions. Such control policies and strategies must include consideration of the cumulative effect on Ontario and other Provinces of all pending SIP revisions. The information set out in this submission should lead the Administrator to conclude that any increase in SO₂ emissions from sources will further impair the Ontario environment and should not be permitted.

Ontario further bases its submission on the undertaking set out above

"to promote vigorous enforcement of existing laws and regulations as they require limitation of emissions from... existing facilities in a way which is responsive to the problems of transboundary air pollution".

This requires that all necessary enforcement action be taken to restrict existing facilities within legally permissible standards. Many sources now seeking SIP relaxations have not been in compliance with the allowable limits.¹

Ontario further relies on the undertaking in the above Memorandum to continue the practice of

"advance notification and consultation on proposed actions involving a significant risk or potential risk of causing or increasing transboundary air pollution".

Ontario submits that the above provisions require E.P.A. to evaluate the cumulative effects of all SIP relaxations on Ontario and other provinces, to give proper notification of the results thereof and to consult thereon.

Indeed existing standards should be enforced "in a way which is responsive to the problems of transboundary air pollution" and consultation should occur in order to assure such enforcement.

On 22 November 1978 the U.S. and Canada signed the Great Lakes Water Quality Agreement of 1978 which provides that the Great Lakes system (of which the affected areas of Ontario are a part) shall be free from substances that will adversely affect aquatic life or are harmful to human, animal or aquatic life (Article III). The Agreement announced the policy of the two nations to develop and implement co-

ordinated planning and management practices by the federal, state, provincial and local governments (Article II).

4.2 Duty of State to protect other States from injurious acts

The principles of international law governing a trans-boundary pollution situation are set out in the Report of the Arbitral Tribunal in the Trail Smelter Arbitration.²

In that case a smelter located in Trail, B.C. was emitting sulphur dioxide which caused damage to areas in the State of Washington. In order to resolve the dispute over liability and damages, the matter was referred to an Arbitral Tribunal established pursuant to an international convention. The decision of the tribunal establishes the principles governing transboundary pollution.

The initial dispute in Trail Smelter concerned a private nuisance claim against a corporation in Canada by residents of the State of Washington. Although the dispute did not directly concern the two governments, they agreed to submit it to arbitration. It was, therefore, accepted that Canada would be responsible for any damages caused by the corporation and that the U.S. was the proper claimant to represent claims by its citizens.

The decision of the Arbitral Tribunal in Trail Smelter establishes the following fundamental principle:

"A State owes at all times a duty to protect other States against injurious acts by individuals from within its jurisdiction...International decisions, in various matters,...are based on the same general principle,..."

In the language cited above, the decision established that the State is responsible to another State not only for the injurious acts and emissions of its government but also vicariously for the injurious acts of its citizens.

In the decision of the Arbitral Tribunal, the principle was also stated in the following language:

"...under the principles of international law, as well as the law of the United States, no state has the right to use or permit the use of its territory in such manner as to cause injury by fumes in or to the territory of another or the properties or persons therein, when the case is of serious consequence and the injury is established by clear and convincing evidence".

A reading of the decision in Trail Smelter makes it clear that the conclusions reached were based on decisions of the Supreme Court of the United States. This point was noted by the Tribunal as follows:

"the law followed in the U.S. in dealing with quasi-sovereign rights of the States of the Union, in the matter of air pollution, whilst more definite, is in conformity with general rules of international law".

The above authority indicates that a State should act in such a manner as not to permit the use of its territory so as to cause injury by pollution to the territory of another. When the context is not compensation being sought, but rather a proposed administrative decision which could lead to increased emissions, we submit that the onus should be on anyone justifying such increases or proposing to approve them to establish that there will be no injury by pollution to the territory of another country.

In any event, Ontario says that the injury it now suffers from acid deposition from U.S. sources and the cumulative effect of the increases proposed in the SIP relaxations now pending make it clear that the case is of serious consequence. Ontario further submits that the information set out in this submission establishes such injury on clear and convincing evidence.

Both U.S. and Canada have adopted Principle 21 of the 1972 Stockholm Declaration on the Human Environment, which says:

"...States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction..."

Further, both the U.S. and Canada have signed the United Nations convention of November 13, 1979 on Long Range Transboundary Air Pollution. In this the parties recognized,

"the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

Ontario says, therefore, that the Administrator should act in such a manner as to cause the United States to comply with the principles of international law stated above. To approach the question of SIP revisions in a piece-meal manner without considering serious consequences to Ontario and other Provinces would be to proceed blindly and contrary to principles of law. In the present case, the Administrator should consider the cumulative impacts of all sources involved in proposed SIP revisions and should reject any revisions which result in increased SO₂ emissions impacting on Ontario or other Provinces.

4.3 S.115 Clean Air Act, Basis of Substantive Law

In addition to the August 1980 Memorandum of Intent and General Principles of International Law, Ontario submits that these proceedings are, or should be, governed by S. 115 of the Clean Air Act. The section is discussed above with regard to access by Ontario to these proceedings. S. 115a reads as follows,

"Whenever the Administrator, upon receipt of reports, surveys or studies from any duly constituted international agency has reason to believe that any air pollutant or pollutants emitted in the United States cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare in a foreign country or whenever the Secretary of State requests him to do so with respect to such pollution which the Secretary of State alleges is of such a nature the Administrator shall give formal notification thereof to the Governor of the State in which such emissions originate."

On January 16, 1981 the Administrator of the Environmental Protection Agency announced that he had reached conclusions adequate to warrant the initiation of S. 115⁶. The reasoning of the Administrator in reaching these conclusions has been set out in correspondence.⁷ Relying on a recent report of the International Joint Commission, the Administrator made the following statement:

"The International Joint Commission which is a duly constituted international agency under Section 115, has recently transmitted a report which addresses the issue of acid deposition. My review of the October 1980 Seventh Annual Report on Great Lakes Water Quality of the International Joint Commission (IJC) leads me to conclude that the IJC has found acid deposition results in significant harm in both the U.S. and Canada and that emission sources in both the U.S. and Canada contribute to the problem through the long-range transport of air pollution. The IJC Report states that '(a)cidic precipitation is one widely known and serious example of a problem associated with the long-range transport of airborne pollutants.' (Report at 49). The Report states that '(v)irtually all of eastern Canada and portions of the northeastern United States experience rains with acidity equal to or exceeding that which can adversely affect susceptible ecosystems. All parts of the

Great Lakes watershed are now receiving precipitation containing 5 to 40 times more acid than would occur in the absence of atmospheric emissions. Many inland lake ecosystems in the most susceptible parts of the Basin may be irreversibly harmed within 10-15 years' (Report at 50). The Report also notes that '(a) substantial portion of the Great Lakes drainage basin is potentially susceptible to acidic precipitation, based on its bedrock geology. The Sudbury, Muskoka and Haliburton areas of Ontario and the Adirondacks of northern New York are among the most heavily impacted areas in the world because their geology offers little buffering capacity to their inland lakes. Some lakes in the Haliburton-Muskoka area have lost 40-75 percent of their acid neutralizing ability in a decade or less. These areas are now being subjected to precipitation which is twice as acidic as that which caused losses of major fish stocks in thousands of Scandinavian lakes.' (Report at 50)."

The Administrator also concluded that new Canadian legislation provides Canada with ample authority to give the U.S. essentially the same rights as S. 115 while emphasizing that this aspect would be subject to ongoing evaluation as to Canada's interpretation and implementation of its legislation.

Ontario submits that all of the sources involved in these proceedings significantly contribute to the air pollution problem identified pursuant to S. 115. It is clear from the wording of S. 115b that the S. 115 process leads to SIP revisions

"adequate to prevent or eliminate the endangerment referred to in sub-section (a)."

As the information set out in this submission establishes that Ontario is already subject to levels of acidic precipitation which seriously impair the environment and affect the welfare of its residents, any increased emissions would be inconsistent with the obligations of the Administrator under S. 115. Those proceedings must lead to substantial reductions to fulfill their statutory objective. Therefore, any increases in emissions in the instant proceedings would compromise the proceedings under S. 115. Ontario submits that in order to carry out the obligation imposed on her, the Administrator must first evaluate in a systematic way and on the basis of the best information available the impact of the proposed increases on Ontario and other parts of Canada.

REFERENCES - CHAPTER 4

1. Table 7.1
2. Trail Smelter Arbitration, American Journal of International Law (1941) 684.
3. Ibid, 713.
4. Ibid, 716.
5. Ibid, 713.
6. Environmental News, January 16, 1981.
7. Letter D. COSTLE to SENATOR G. MITCHELL, January 13, 1981.

ESTABLISHING THE CAUSE OF ACID DEPOSITION IN ONTARIO5.1 Introduction

This chapter reviews the causes of acid deposition in Ontario and shows how a significant amount of this deposition (in both the dry and wet forms)¹ comes from the states mentioned in this submission. The review draws from many studies of acid deposition and long range transport which are currently in the technical literature, and each section in the chapter discusses one step in establishing how the emission sources of SO₂ are causing a part of this deposition. Subsequent chapters will discuss the effects of this deposition and the significance of the proposed SIP relaxations for SO₂ emissions on Ontario's environment. The two final chapters will show how Ontario is pursuing a policy of drastically reducing its own SO₂ emissions, as well as requesting similar levels of reductions from neighbouring jurisdictions.

It is important to emphasize that a reduction of SO₂ emissions is needed on an eastern North American basis to eliminate the damage caused by acid deposition. In decades past, environmental protection of air quality was approached on a "local" rationale -- that is, airsheds were thought of as small areas surrounding urban zones or rural industrial activity. However, as this chapter will demonstrate, the

protection of the environment from acid deposition (as well as from other problems such as oxidants) requires a change in thinking patterns. An "airshed" can no longer be considered as an entity having localized boundaries and subject to localized styles of management or regulation. The "airshed" is common to many states and provinces of the U.S. and Canada, and pollution control to protect the environment and health of people in that airshed must be a shared responsibility of all parties in that airshed. Chapter 8 of this submission will clearly illustrate why action on the part of one jurisdiction such as Ontario to lessen SO₂ emissions is fruitless unless its neighbours -- the midwestern and eastern states of the U.S. -- also take action.

The Government of Ontario knows that the EPA is undertaking studies of air pollution problems in regional, multi-state airsheds.²⁻⁵ This is encouraging, but inadequate from our point of view. A glance at a map of Ontario (see Map 2.1) shows that the most environmentally sensitive part of Ontario is literally wedged between the middle of a highly industrialized group of states. Our part of the regional airshed is intimately related to the U.S. portion of the same airshed; therefore, Ontario's environment must be studied, assessed, and protected in close concert with the U.S.

Ecological damage resulting from the intimacy of the airshed relationship is not limited to acid deposition. Concern has been noted over the past two decades about

oxidant damage in Ontario^{6,7} due to sources in distant areas, and a recent IJC report⁸ highlights growing concern that the atmospheric deposition of organic compounds such as PCB's and pesticides into the Great Lakes is a major source of contamination of these water bodies. The IJC further states that much of the deposition is likely due to distant sources.

Ontario submits that the existence of these other regional air quality problems is further compelling evidence that jurisdictions must consider pollution effects and related control strategies on the large-scale regional airshed basis.

5.2 Description of Weather Systems Affecting Ontario

Ontario is a large province, and air masses move across the various parts of the province from different directions. Because the acid deposition problem is documented to be greatest in the Southern part of Ontario (that is, the area approximately covered by region 1 of Map 2.1), this chapter will focus on weather systems moving over this part of the province. This section discusses the evolution of systems bringing in both precipitating and non-precipitating air masses, as these systems contribute to wet and dry acid deposition respectively.

Wind directions into and across Ontario have a westerly prevalence with a higher percentage frequency north of west in the winter and a higher percentage frequency south of west in the summer. As a low pressure area bringing precipitation moves in, it is preceded by a southerly circulation of warm humid air. It is followed by a cold frontal passage and a northerly flow of relatively dry air. The high pressure area which follows the low will return the winds to a south and southwest direction. While dry air may be from any direction, air masses leading to precipitation most frequently originate from the south.

5.3 Dry Acid Deposition and the Weather

5.3.1 Background

Weather conditions that control air movements play an important role in the long distance transport of pollutants that contribute to the dry and wet deposition of acidic materials.

Whenever a pollutant is released into the lower atmosphere, it may either (a) be deposited on the surface near the source (i.e. within about 50 km) through the actions of gravity, turbulent diffusion, rain, or snow, or (b) undergo chemical transformation and be deposited locally or (c) it may be transported in either its original or transformed state many hundreds or thousands of kilometers by the wind before falling to the earth. Recent research⁹⁻¹¹ has done much to enhance the understanding of how some of these

pollutants react as they are transported, but the exact mechanisms are still not completely understood. Nevertheless, the general features are well enough delineated to link the precursors of acid deposition with the deposition itself.¹²⁻¹⁴

In the case of dry acid deposition, high ground level concentrations of sulphates and/or nitrates are a good indicator that the dry acid deposition process is likely.¹⁵ In what follows, conditions giving rise to high levels of acid deposition and the frequency of these deposition episodes will be discussed.

5.3.2 Evidence of Contributions from Southerly and Northerly Sources

In the past decade, there have been numerous studies which have shown that pollutants such as sulphur dioxide, sulphates, ozone, and nitrates are transported over hundreds or even thousands of kilometers by the winds before they are dry-deposited to the earth's surface. A number of these studies¹⁶⁻²⁴ are concerned with the long-range transport of pollutants into Southern Ontario from the highly industrialized regions of the United States south of the Great Lakes.

One of the first studies that indicated the long-range transport of pollutants into Ontario was undertaken in response to ozone damage to tobacco crops north of Lake Erie.⁶ This study concluded that the flecking of tobacco plants occurred when the air masses containing high ozone

concentrations in Ontario had been over the industrial areas of the United States south of Lake Erie six to twelve hours earlier.

More recent studies^{16,19} have shown that summer ozone concentrations are highest in Southern Ontario during a flow of warm air from the south which occurs with the passage of the northwest sector of a high pressure area. The number of days with high levels of ozone varies considerably from year to year, but the frequency is significant. For example, in 1978 there were 43 days of elevated levels while in 1979 there were 14. The ozone was often associated with high levels of sulphates. Back trajectories of the air parcels show that air arriving in Southern Ontario with high ozone and sulphate concentrations originated south of the Great Lakes. In contrast, air of northerly origin has been demonstrated to have much lower pollutant concentrations. U.S. studies have shown that high pollutant levels in the northeastern United States were associated with air flows from the Ohio Valley and comparably clean air was associated with a northerly circulation from Canada.²⁵⁻²⁹

5.3.3 Specific Examples of Pollution from the South

The long range transport of acid-deposition-related pollutants over eastern North America is often evident from aircraft. During sunny days, haze in the lowest few thousand foot layer can be seen extending for hundreds or thousands

of kilometers covering both urban and rural areas. Satellite photographs of eastern North America have shown large hazy air masses present in cloud-free regions.³⁰ Further investigations have revealed that this air is characterized near the surface by low visibility and high concentrations of sulphate particles and ozone. By analyzing a series of these photographs, the path history of the "smog area" can be reconstructed.

The history of one such event (August 16-28, 1976) showed the "smog area" south of the Lower Great Lakes and spreading over the entire Lower Great Lakes region by August 22nd. A weak cold front pushed the "smog area" southward on the 23rd, but it again moved northward across Southern Ontario on the 26th. Particulate sulphate concentrations exceeded 40 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) at several Ontario sites during this period. In addition, the origin of the sulphate-laden air, reported in an area extending from Windsor to Quebec City, was demonstrated to be the Ohio, Pennsylvania, and West Virginia regions.¹⁹ The concentrations of sulphates reported at ground level over Ontario, Quebec and the northeastern United States on August 16, 22 and 28 are shown in Figures 5.1, 5.2 and 5.3. These figures indicate that the measured levels of sulphates caused the reduction in visibility that was evident in the satellite photographs.

A second example shows that sulphates may occur in the absence of ozone, in the winter season. One such episode occurred in February 1979. A prolonged cold spell in Southern Ontario was broken with the onset of southerly winds that brought warm air into and across the province,²⁴ following the passage of a slow eastward moving high pressure area from southwest of the Great Lakes to the Atlantic Seaboard. As the winds shifted to the southerly direction, sulphur dioxide concentrations began to rise on February 19 in the southwest part of the province. By mid-day of February 20, they had spread to Ontario's eastern areas. The rise in sulphur dioxide concentrations was most pronounced at rural monitoring sites where sulphur dioxide concentrations are normally near zero. Particulate sulphate concentrations were also unusually high, accounting for around 30% of the suspended particulate matter at some sites. The maximum sulphate concentration during this period was $67.5 \mu\text{g}/\text{m}^3$. Trajectory analyses indicated that the high concentrations of these sulphur compounds were associated with air movement from south of the Great Lakes. The Ontario Air Pollution Index,³¹ which is based on sulphur dioxide and suspended particulate concentrations and is designed to protect the health of the Ontario public, rose above the Advisory Level in three Ontario cities during this time period. As a result, Ontario industries were asked by the Ontario Ministry of the Environment to curtail emissions in compliance with Ontario's Environmental Protection Act. The subsequent investigation²⁴ showed that approximately 50% of the pollutants originated in the United States.

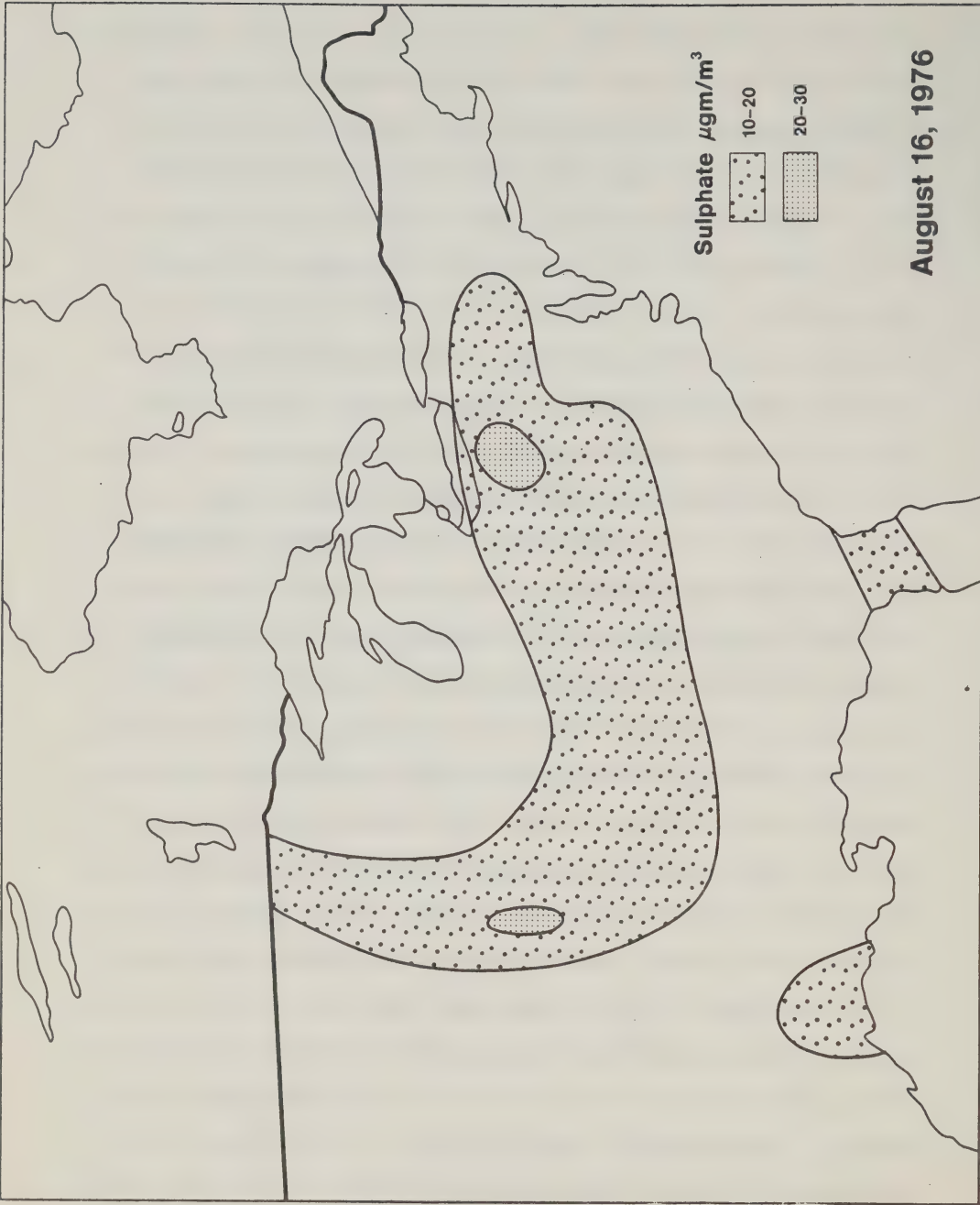


Figure 5.1 Day 1 of a typical episode demonstrating development of high sulphate concentrations over Ontario.

August 22, 1976

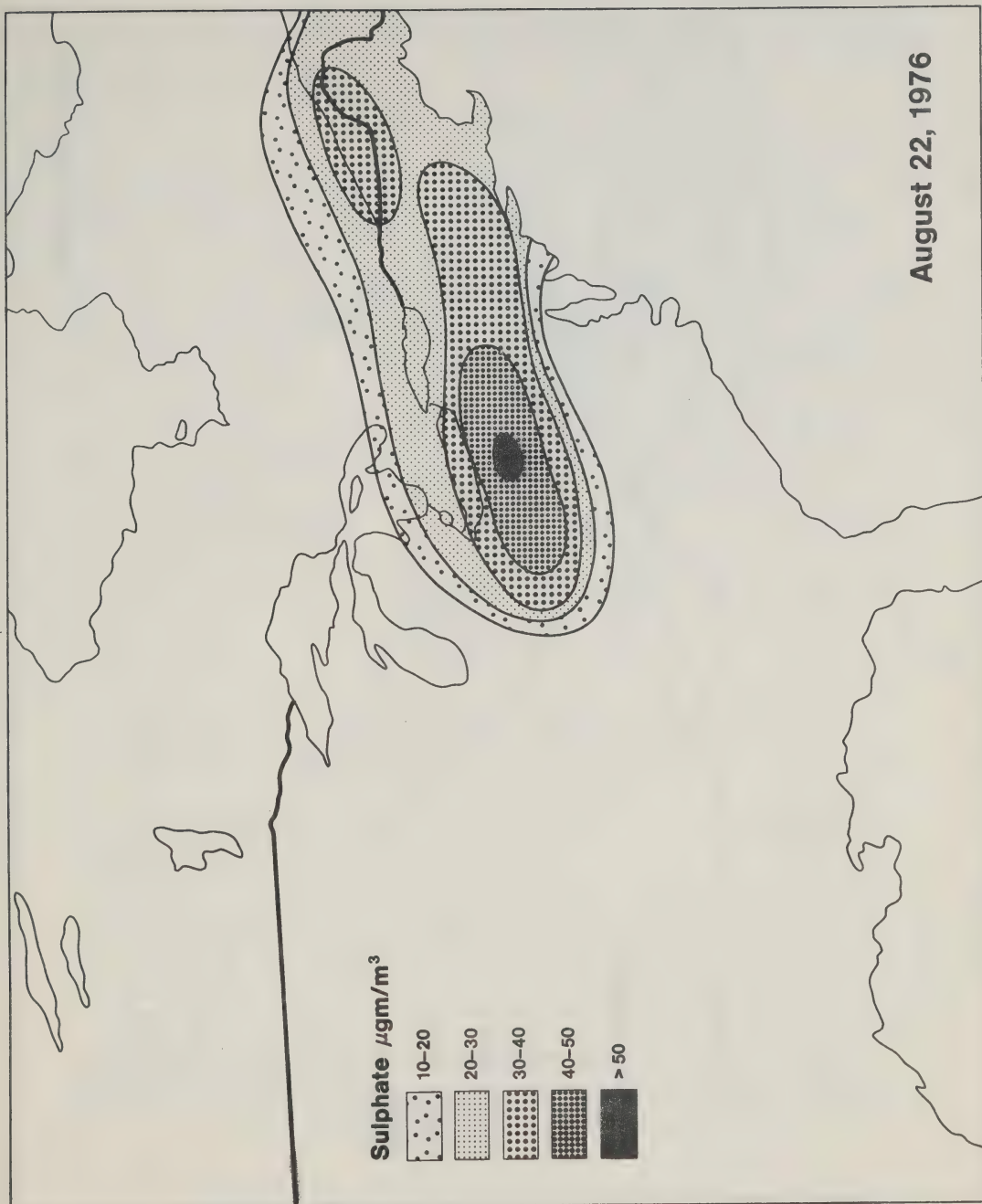


Figure 5.2 Day 7 of a typical episode demonstrating development of high sulphate concentrations over Ontario.

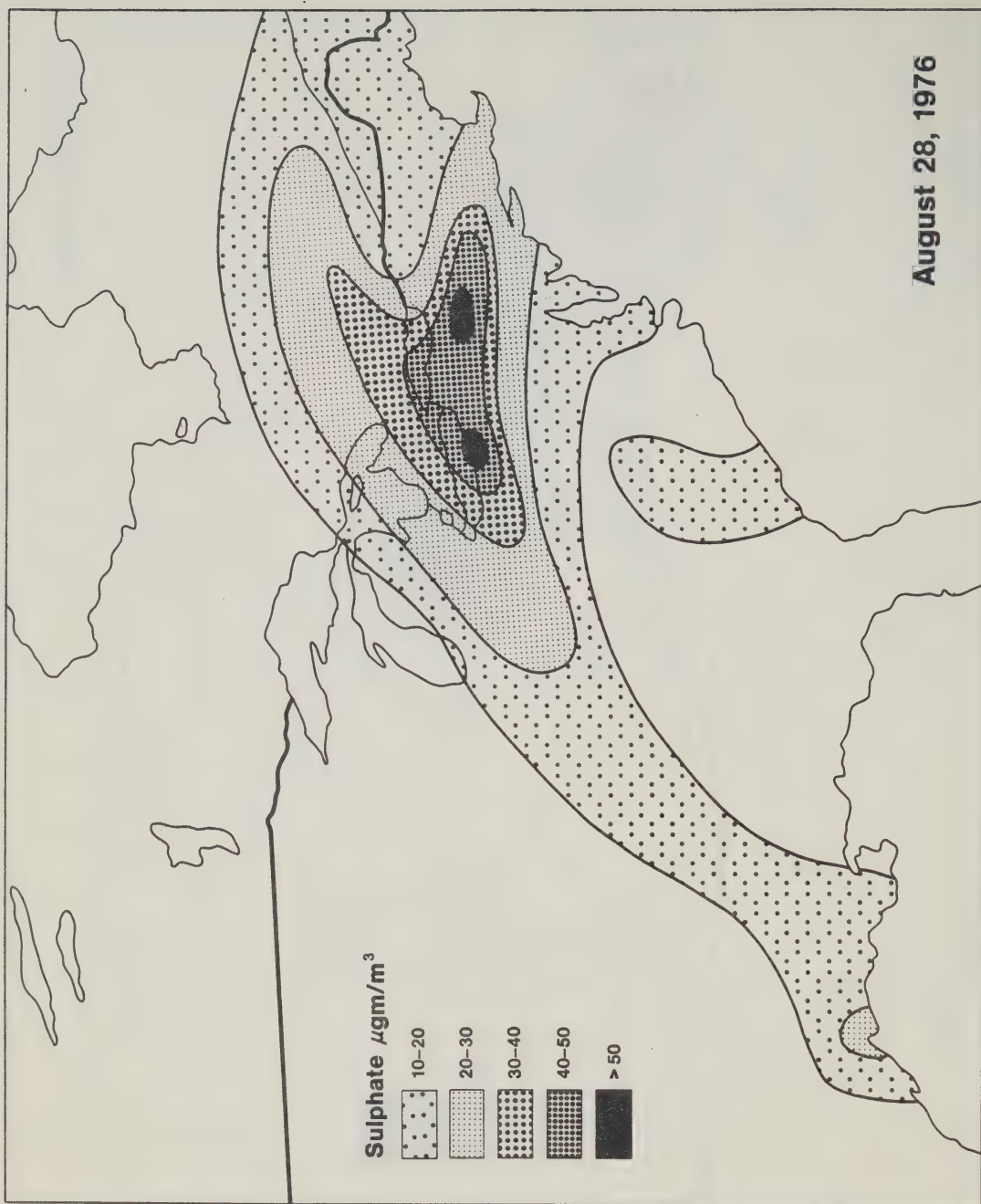


Figure 5.3 Day 13 of a typical episode demonstrating development of high sulphate concentrations over Ontario

Therefore, the importation of U.S. pollution was directly responsible for unacceptable air quality in Ontario, and this U.S. pollution forced a temporary curtailment of Ontario industrial operations.

Studies of particulate nitrate^{22,23} have shown that nitrate concentrations exhibit similar patterns to sulphate and ozone with high concentrations occurring during periods when air flows into Southern Ontario from the south. Detailed study of periods of widespread elevated nitrate concentrations (in excess of $10 \mu\text{g}/\text{m}^3$) showed air originating south of the Great Lakes. Further analysis has shown that when an air mass moves over Southern Ontario after having passed over the States south of the Great Lakes, nitrate concentrations are nearly twice those measured when the air mass originates from the north.

5.4 Wet Acid Deposition and the Weather

5.4.1 Background

Pollutants can be removed from the air and deposited to the ground by precipitation (i.e. rain, fog, or snow). This is known as wet deposition. In the case of wet acid deposition, the substance of concern is hydrogen ion. The dissolved oxides of sulphur and nitrogen in precipitation give rise to its acidity.

As with dry deposition, recent studies^{32,33} have advanced the state of knowledge regarding how precursor compounds are transformed, removed and deposited by precipitation. The relationships are complex, but a reasonable layman's summary can be presented as follows: (a) the primary pollutant emissions consist largely of SO_2 and/or NO_x ; (b) deposition mechanisms may "bring down" part of the emissions locally if the meteorological conditions are appropriate, or the pollutants may be carried long distances; (c) chemical transformations may occur during transport via differing mechanisms, depending on whether the air is dry or moisture-laden; and (d) wet deposition occurs with precipitation at large distances from the sources.

5.4.2 Measuring Acidity in Precipitation

Measurements of the wet deposition of acidity are obtained by the chemical analysis of collected rain and snow samples. Scientists gauge the acid and base strength of a solution by a parameter called pH which is a logarithmic measure of the hydrogen ion concentration on a scale ranging from 1.0 to 14.0. On the pH scale, a chemically neutral solution has a value of 7.0 which is mid-way on the scale. The greater the acidity, the lower the pH value. A change of one pH unit downward defines a tenfold change in the hydrogen ion concentration, or a tenfold increase in acidity; a change of two is a hundredfold. If for example, a pH is 4.0 it is 10 times more acidic than a pH of 5.0; a pH of 3.0 is a hundredfold more acidic than a pH of 5.0.

There are several precipitation monitoring networks operating in North America. Figure 5.4 illustrates pH isopleths based on data from two of these networks for 1979.³⁴ The normal pH level of precipitation is 5.6; that is, slightly acidic. However, when the precipitation contains oxides of sulphur and nitrogen, its acidity increases. Figure 5.4 indicates that the acidity levels of precipitation are very severe in the Northeastern U.S. and Southeastern Canada, with the highest levels in the vicinity of the Lower Great Lakes where the pH is near 4.0. This acidity is thus about 40 times that of normal precipitation.

Precipitation at a pH level of less than 4.5 (about 10 times more acidic than normal) will cause damage to sensitive lakes, as discussed in Chapter 6. The data for 1979 shows an area of damaging acidic precipitation over most of Ontario, except the northwest portion, over southwestern Quebec, and over most of the northeastern United States. It is this area that we have shown to be subjected to the long range transport of pollutants from sources that are the subject of the Proceedings. Simulation modelling results, which follow in Chapter 7, will quantify the contribution of these sources.

5.4.3 Evidence of Contribution from Southerly and Northerly Sources

The most frequent type of storm system which gives rise to precipitation in the southern portion of Ontario first

passes over the areas of high emissions in the Great Lakes States.³⁵ These storms occur with a frequency of 15 to 25 times per annum. A typical example, is the track of a low pressure area originating in Eastern Texas, as shown in Figure 5.5. The low pressure system intensifies as it moves north-eastward towards the Great Lakes, bringing warm humid air northward from the Gulf of Mexico. This air passes across the industrialized Ohio River Valley, becoming laden with oxides of sulphur and nitrogen prior to entering Ontario and the Northeastern United States. A significant proportion of these pollutants is chemically transformed during travel to particulate sulphates and nitrates, which are eventually scavenged (i.e. removed) from the air by tiny water droplets. These, after growing in size, form acidic precipitation which can be deposited onto Eastern Canada or the Northeastern United States.

The significance of this situation has been well documented by an Ontario Ministry of the Environment study.³⁶ Weather maps were analyzed along with precipitation samples taken over a three year period in the Muskoka-Haliburton region, an environmentally sensitive area of South-Central Ontario. This region lies about 200 km North of Toronto and about 200 km Southeast of Sudbury, where Ontario's largest smelter sources of SO_2 are located. Back trajectory analyses³⁷ showed that 75% of the precipitation events at the site were associated with air masses arriving from the south and southwest octants. Furthermore, analysis of the precipitation samples showed that approximately 80 per cent of all acid

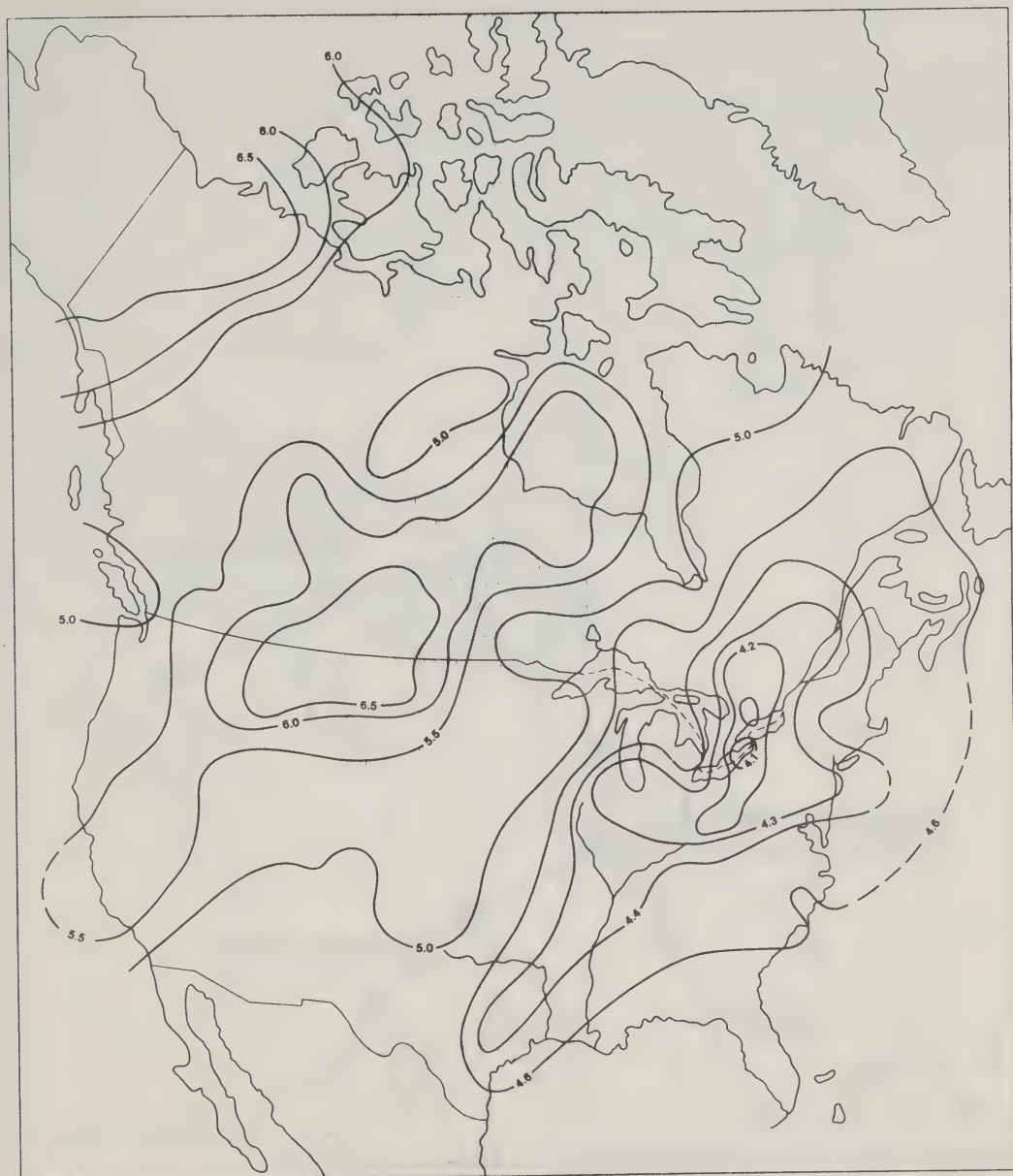


Figure 5.4

NATIONAL ATMOSPHERIC DEPOSITION PROGRAM-NC141

pH Annual Average-1979
Precipitation-weighted
NADP & CANSAP DATA
February, 1981

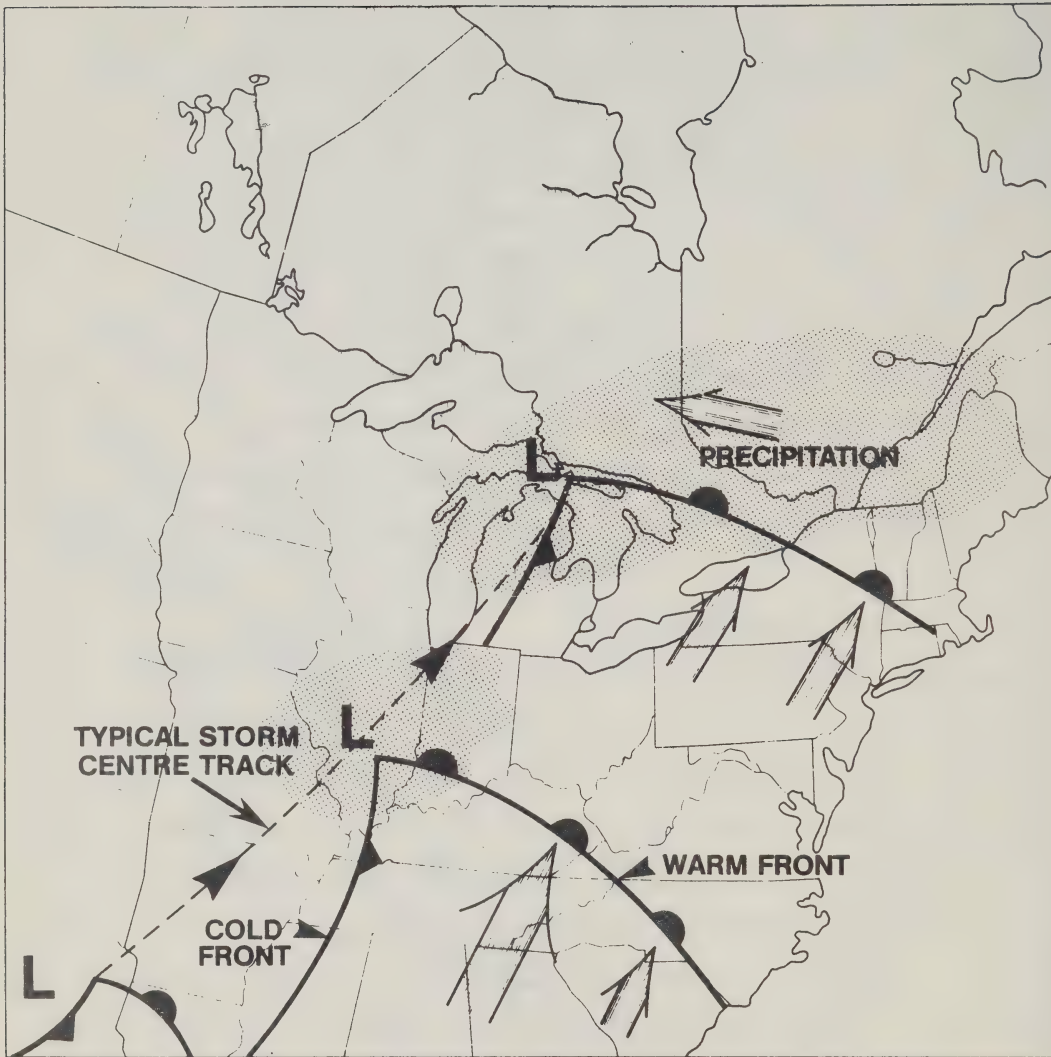


Figure 5.5 Typical storm track across Central United States and into Ontario.

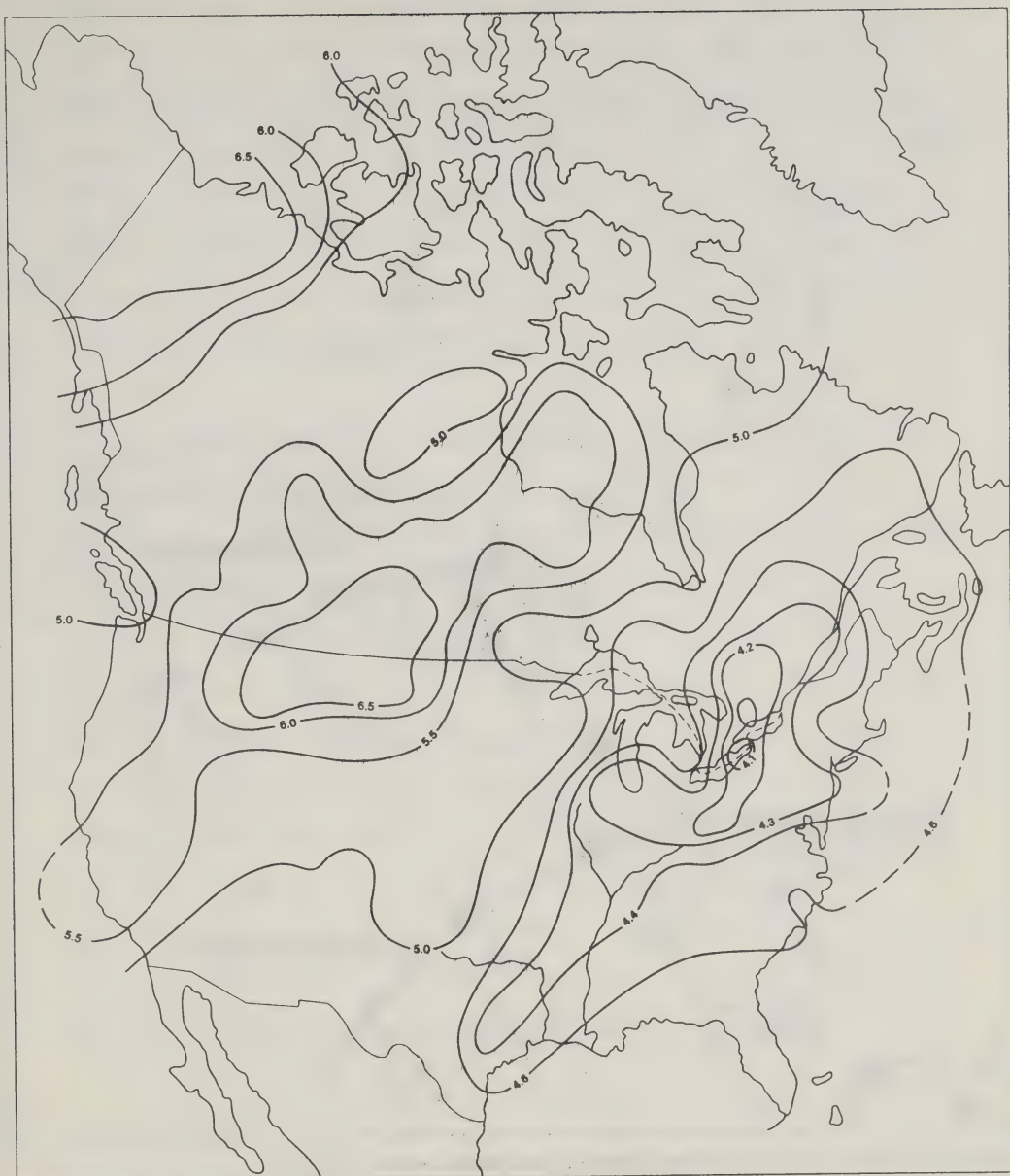


Figure 5.4

NATIONAL ATMOSPHERIC DEPOSITION PROGRAM-NC141

pH Annual Average-1979

Precipitation-weighted

NADP & CANSAP DATA

February, 1981

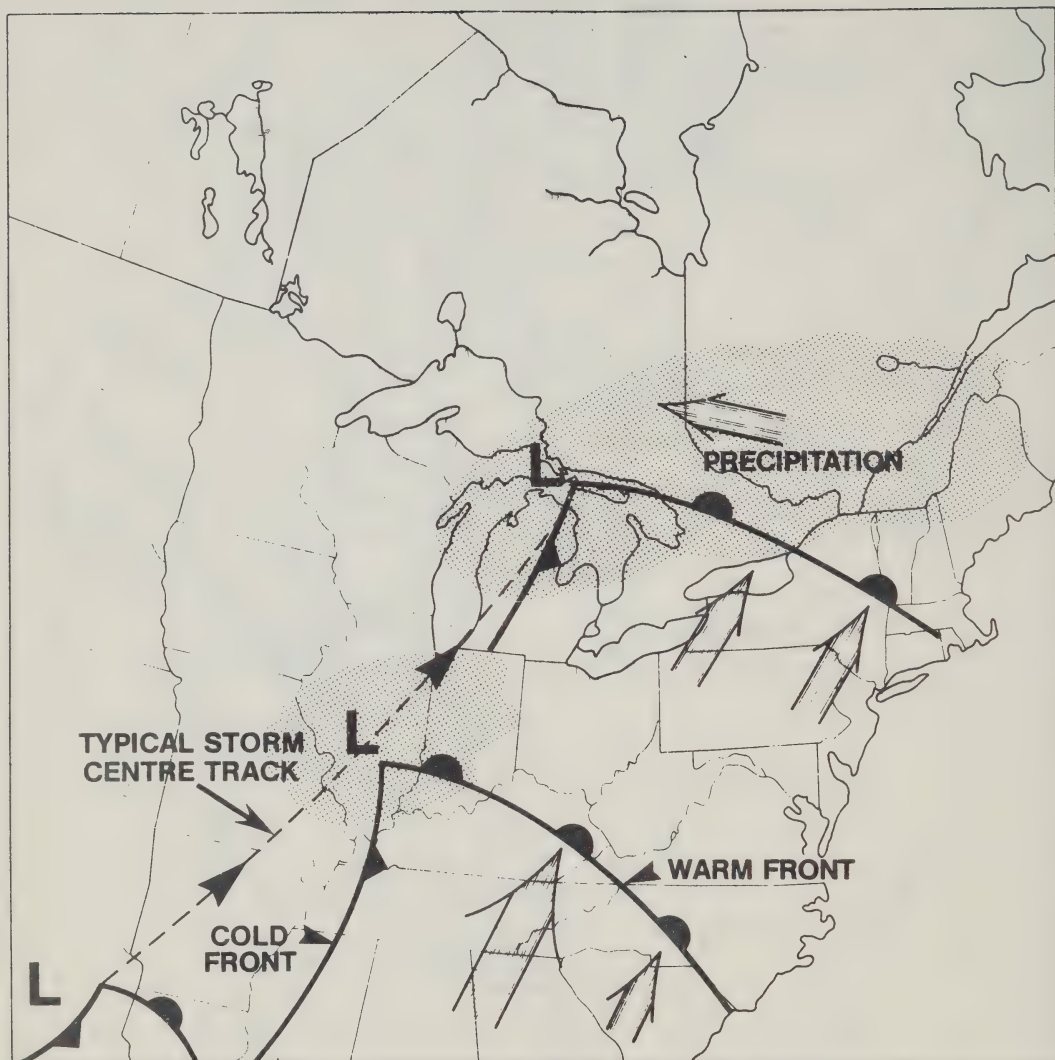


Figure 5.5 Typical storm track across Central United States and into Ontario.

which was wet-deposited came with air masses from the south and southwest. While Canadian sources to the south also contribute to this percentage, the relative magnitude of these sources is very small compared to the size of the U.S. emissions south of Muskoka-Haliburton. Thus, it is reasonable to assign most of the 80 per cent figure to U.S. sources. Other studies^{20,38} have also shown that the high acidity in precipitation over Ontario occurred in conjunction with air masses that originated in the United States.

A second study done by the Ontario Ministry of the Environment reinforces the above conclusion.³⁹ A series of wet deposition measurements (i.e. precipitation event samples) were taken in the Sudbury area, and careful records were kept of the weather conditions and the direction taken by the smelter plumes. While interesting results were obtained concerning the amount of wet deposition due to the local smelter plumes, the study also demonstrated that the pH of precipitation associated with northerly winds was on average 4.6, while the pH value of precipitation associated with southerly winds was 4.2. Therefore, the acidity of precipitation related to southerly air masses was more than twice as great as that of precipitation from the north.

5.5 Summary

This chapter has presented evidence from a variety of fields which clearly and convincingly documents the fact that the states containing the power plants in these reports

are causing a significant amount of the acid deposition occurring in Ontario. Chapter 7 will quantify the part of this deposition due to the 20 power plants under consideration, and Chapter 6 will discuss the effects this deposition is causing, but it should be clear from this chapter that:

- . weather systems can frequently move air masses over long distances;
- . emissions of SO_2 and NO_x from U.S. sources are mixed into these air masses and react as the air masses are transported to form acidic compounds;
- . these air masses can then either dry-deposit or wet-deposit acidic material onto Ontario's sensitive areas with a significant frequency;
- . experimental measurements of wet deposition, and meteorological analysis coupled with air quality measurements, verify that the U.S. has a significant impact on the deposition in Ontario.

These points all reinforce the necessity of the E.P.A. Administrator to work closely and conscientiously with other jurisdictions sharing the northeastern continental airshed in order to judge before the fact whether or not SIP relaxations will adversely affect the environment anywhere in that airshed.

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EFFECTS OF ACID DEPOSITION ON ONTARIO'S
AQUATIC SYSTEMS

Sensitive aquatic systems which receive acid, both directly and indirectly from precipitation, can suffer chemical and biological damages. This chapter discusses the nature and magnitude of these effects in Ontario as evidenced through research on the province's aquatic ecosystems.

6.1 General Nature of the Lake and River Acidification
Process

Acids falling on the earth's surface may be neutralized by chemical reaction with basic materials in the soil and water. Soils with large amounts of basic material, such as limestone, can neutralize the acids for indefinite periods of time with only minor changes in the chemical composition of the runoff. If, however, the soils have little capacity to neutralize the acid, for example, Precambrian rock, the acid loading can exceed the neutralizing capacity and runoff water will be acidic with consequential biological damage in streams and lakes.

The alkalinity of lake and river water is a chemical measure of its capacity to neutralize acid. The greater the alkalinity, the higher the pH value will be

and the greater the capacity to neutralize acid. The alkalinity is often referred to as the buffering capacity of the water. Lakes in areas of limestone soils have high alkalinities and pH values generally above 7.0. By contrast, unpolluted lakes located in hard rock geological conditions, such as the Precambrian rock area of Ontario, have low alkalinities and pH values generally in the range of 6.0 to 7.0. While these lakes are on the acidic side of pH 7.0, they still have healthy aquatic life and vigorous fish populations.

Lakes with low alkalinity are regarded as sensitive to the effects of acid rain since they have a low capacity to maintain (or buffer) the pH at acceptable values when excessive acid is added from the atmosphere.

When excessive acid loadings from the atmosphere are applied to sensitive areas, the pH of the runoff may be reduced to values well below 6.0 for a few weeks time during spring snow melt or for a few hours or days during heavy summer and autumn rains. In addition to these short term effects, the soil alkalinity or buffering capacity can be slowly used up by the acid and therefore, the pH of the streams and lakes is reduced throughout the year. Lakes which suffer short term pH depression or have their summer pH values slightly reduced are called "acid stressed" lakes.

Over time, the acid loading can virtually exhaust the neutralizing (or buffering) capacity of the soils in sensitive areas and the runoff can become nearly as acidic as the rainfall itself. When the pH of streams and lakes falls to values of about 4.5 or less, fish populations will be essentially absent and the waterbody is called "acidified".

Therefore, the ultimate result of deposition of acids in sensitive areas is acidification of the surface water with virtually complete destruction of aquatic life except for some attached algae and mosses growing on the lake bottom. These effects have been well established for lakes and rivers in Scandinavia affected by acid deposition.²

6.2 Research Approach to Aquatic Effects

Under the current patterns of acidic precipitation, virtually all of the lakes located in Precambrian rock in Ontario are being subjected to acid loadings above "background" levels. Precipitation with pH near 5.6, the value expected for equilibrium with atmospheric carbon dioxide, contains about 2.5 $\mu\text{eq/l}$ of acid (hydrogen ion). The observed concentrations in bulk deposition

are about 11 $\mu\text{eq/l}$ at Kenora* (4 times the "background" level²³ and up to 70-90 $\mu\text{eq/l}$ in the important recreational areas of Muskoka-Haliburton** (28-36 times the "background" level²¹). For several years, environmental studies have been undertaken in these areas designed to determine the resulting water quality and biological responses in the lakes and streams. Data presented in this section are derived from these studies.

The lakes, rivers and watersheds themselves are the ultimate "collectors" of atmospheric pollution deposited by wet and dry mechanisms. One research approach has been to consider lakes and watersheds as giant collectors, which has led to establishing "calibrated watersheds", which are combinations of watersheds, streams and lakes under intensive measurement. The calibrated watersheds are the prime source of information on acid rain effects.

Hydrologic weirs (Figure 6.1) are set up on the streams entering and leaving a particular study lake. The flows of water and dissolved substances are accurately measured entering and leaving the lake and these are

*Located in Northwest Ontario, Northeast of the Ontario-Minnesota Border. Area Code 2 Map 2.1.

**Located in South-Central Ontario. Area Code 1 Map 2.1.

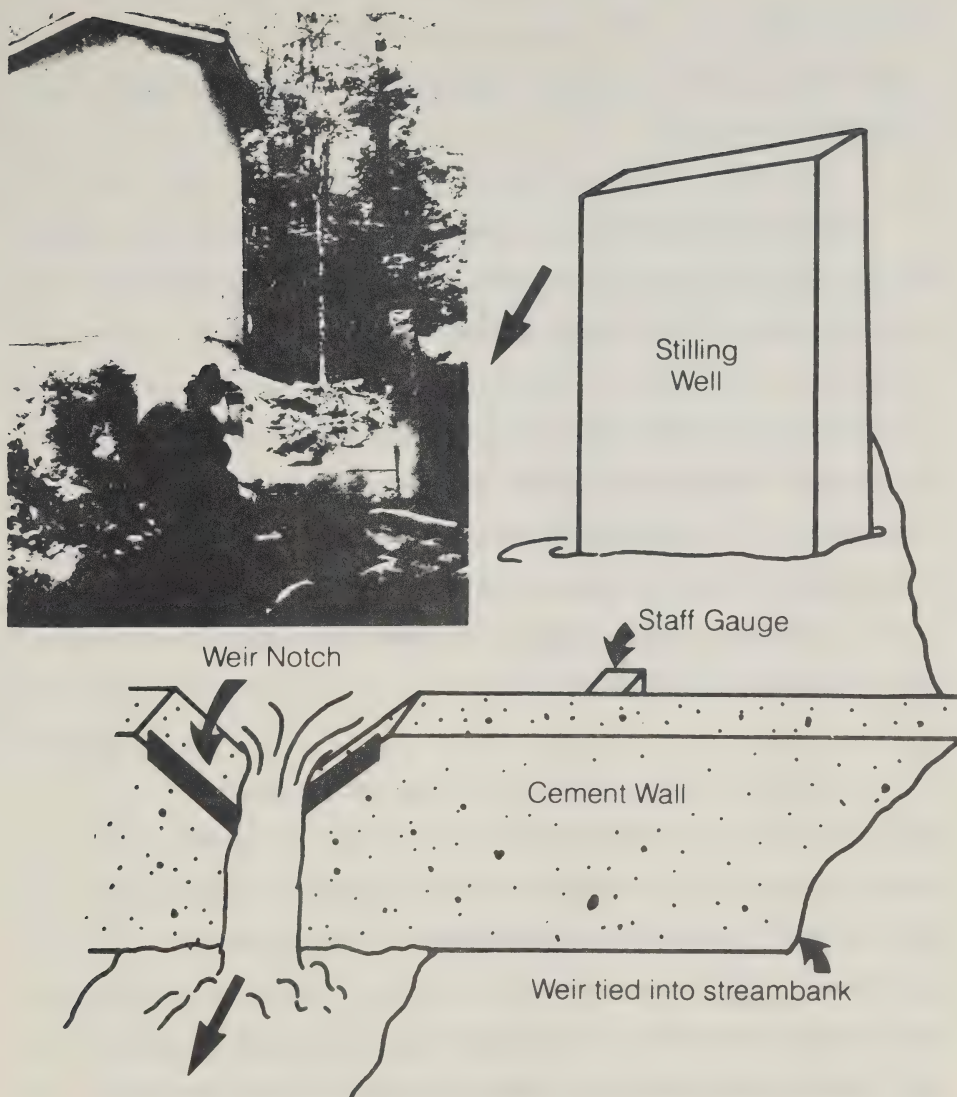


Figure 6.1 Actual and schematic examples of a weir designed to accurately record the flow of water in streams. Water samples are frequently collected for chemical analysis and concentrations and total amounts of chemical constituents passing through the weir are calculated.

combined with the best possible measures of atmospheric inputs and of water loss by evaporation to calculate "substance budgets".

The difference between the inputs measured by the budgets and the inputs measured from wet deposition can give estimates of dry deposition.

The calibrated watersheds are subjected to detailed biological sampling and thus, serve to quantify the chemical and biological effects of pollutant deposition. Relationships established by detailed studies can be extrapolated to large numbers of lakes for which less total data are available.

Calibrated watersheds have been established at many locations such as Kenora, Sault Ste. Marie and Dorset in Ontario, Laurentide Park in Quebec, Kejimikujik Park in Nova Scotia, Hubbard Brook in New Hampshire, and Sagamore Lake in New York. For each study site, a data base of atmospheric loadings and resulting aquatic and terrestrial effects is being compiled. Conclusions regarding effects are drawn from comparisons between areas and from long term observations in each area. Extensive results for Ontario are available from the Kenora and Dorset study locations.

6.3 Observed Effects of Acid Rain in Ontario

6.3.1 Water Quality

Some lakes near Sudbury, Ontario, where nickel and copper smelters have discharged large amounts of sulphur dioxide since the early 1900's, have been acidified by atmospheric deposition of acids^{4,10}. The problem was regarded as "local" and was addressed by reducing emissions and by commissioning the world's highest smoke stack in 1972 to utilize the dilution capacity of the atmosphere for the largest single sources in the area. Ground level sulphur dioxide concentrations due to the local sources had caused discomfort to people and damage to vegetation and both problems have essentially been eliminated by the control programs.

The Sudbury situation is famous because of its size, particularly the INCO Ltd. smelter, but it is far from unique. During the 1970's hundreds of other plants and industries were built in the United States and Canada which utilized high stacks to disperse wastes. Emission reductions were seldom applied; the atmosphere was expected to solve the "problem".

The overall result is that today in North America there are hundreds of atmospheric sources of sulphur and nitrogen oxides from the burning of fossil fuels and non-ferrous smelting operations, all depending on atmospheric dilution to resolve part of the waste problem.

In recent years it had become well understood that the acid rain problem in Ontario was not confined to the Sudbury area and that the Sudbury sources were only a small part of the total emissions to the atmosphere leading to the acid deposition in Ontario.

In most parts of the Precambrian Shield, the acids (hydrogen ions) from atmospheric deposition are neutralized during most of the year. Retention (neutralization) of hydrogen ion has been measured at 88% and 98% on an annual basis at Kenora and Dorset respectively.^{22,23}

However, many detrimental water quality effects are being observed. The hydrogen ions stored in the snow runoff in the spring thaw and most of the total annual acid input occurs during the spring melt. The large volume of water, coupled with less chance for interaction with the soil, which may be frozen, results in shock loadings of acid to streams and to the surface waters of lakes.

Jeffries¹⁷ compared pH values of a series of small streams and lake outflows at Dorset before and during spring runoff. (See Table 6.1). At the very minimum, the surface waters of the entire lakes were acidified during this period of time. The lowest pH values, 4.8 - 5.0, observed in lake outflows, are within a range capable of causing damage to aquatic life, particularly to fish. As much as 76.6% of the measured yearly acid discharge from the watersheds ran off in April. Figure 6.2 shows a typical hydrograph for one of these streams, emphasizing the high spring water flow, high acid discharge, and low pH values. Scheider²² further demonstrated that the pH of streams was depressed for periods of a few hours during times of heavy runoff during the summer months (Figure 6.3).

TABLE 6.1

pH OF STREAMS IN MUSKOKA-HALIBURTON, ONTARIO, CANADA:
 STREAM pH IS GIVEN PRIOR TO SPRING RUNOFF (MID-MARCH 1978)
 AND AT MAXIMUM RUNOFF (MID-APRIL 1978)

Annual Average Alkalinity data from Scheider (Pers. Comm)

Waterhsed	Annual Average Alkalinity µeq/l	Stream Number	pH	
			Mid-March	Mid-April
Harp Lake	96	3	6.1	5.1
		3A	6.0	5.6
		5	5.9	4.8
		6	6.2	5.3
		6A	5.4	5.0
		Outflow	6.3	5.0
Dickie Lake	55	5	4.6	4.3
		6	4.6	4.4
		11	4.9	4.1
		Outflow	5.6	4.9
Chub Lake	61	1	5.8	5.1
		2	5.2	4.7
		Outflow	5.5	4.8
Red Chalk Lake	92	1	6.1	5.6
		2	4.5	4.3
		3	6.0	5.5
		4	6.2	5.5
		Outflow	6.1	5.9

Partial Table From: Jeffries et al., 1979

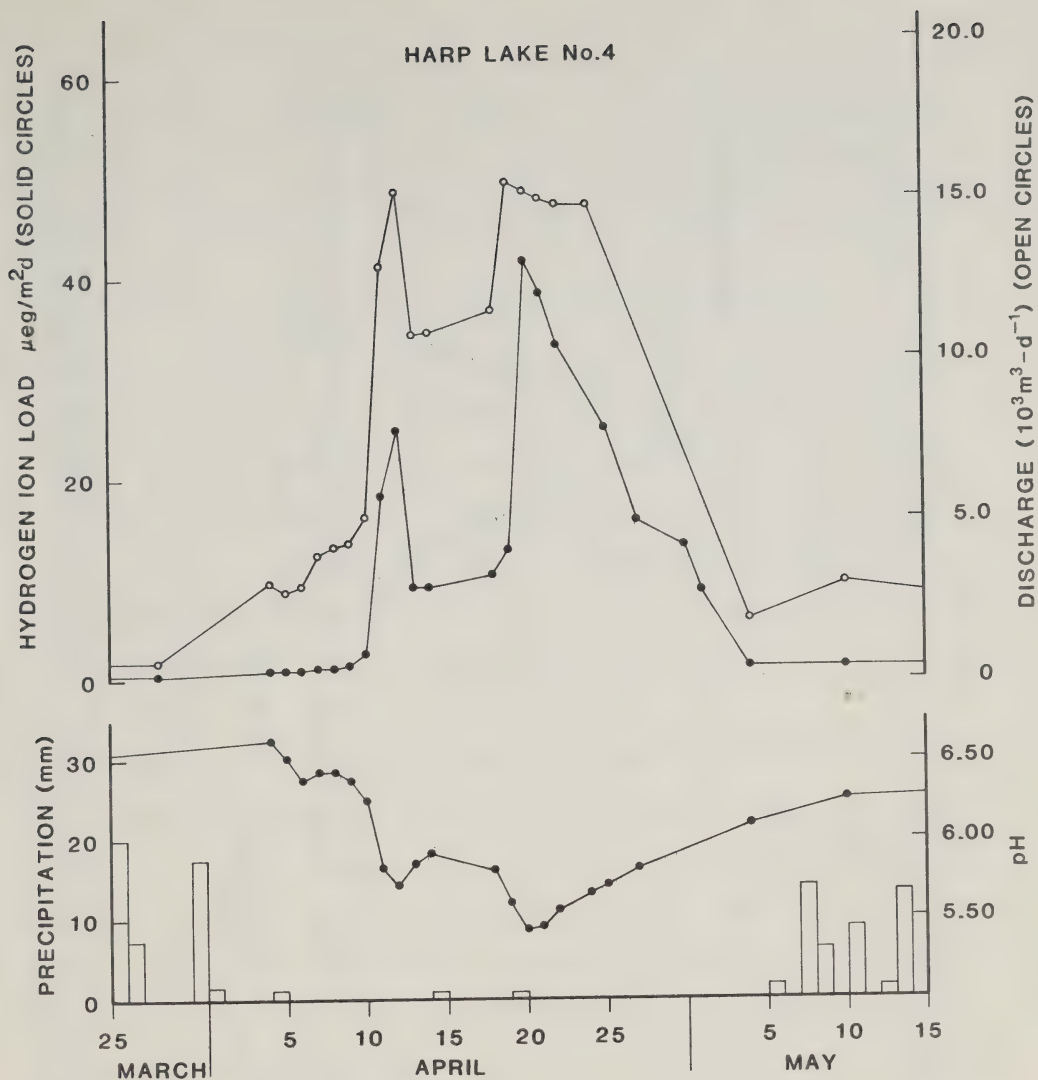


Figure 6.2 "Spring pH Depression" of a Stream

Graph illustrating "spring pH depression" in one of the six inflowing streams to Harp Lake, a study lake in Muskoka. As the spring runoff increases the amount of water, the acidic melted snow causes the stream pH to drop, producing severe chemical "shock" effects on aquatic life.

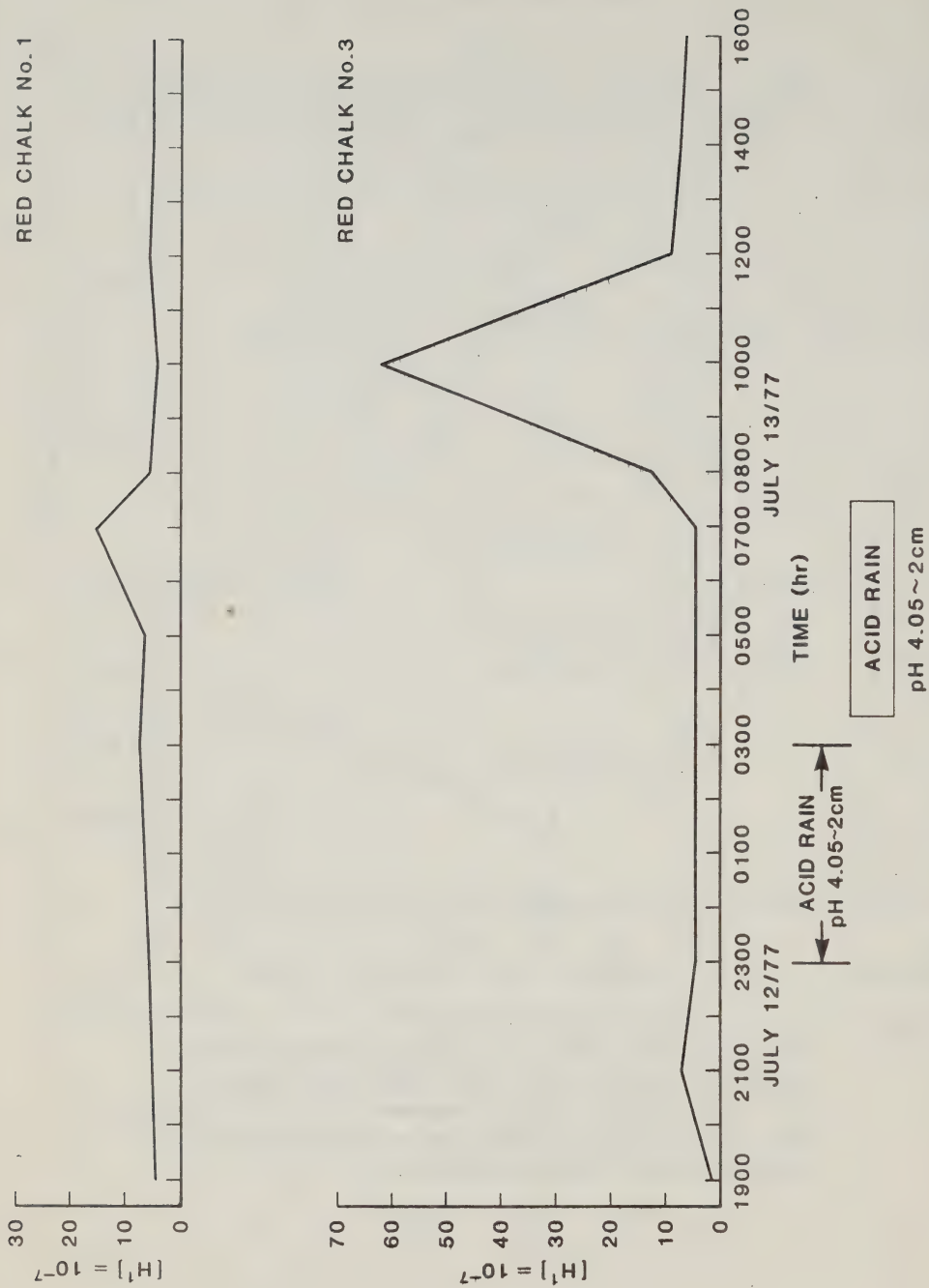


Figure 6.3 Hydrogen ion content of streams draining Red Chalk Lake watersheds No. 3 and No. 1 (Dorset, Ontario) showing effects of a 2cm rainfall (pH 4.06) between 11:00p.m. July 12, 1977 and 3:00a.m. July 13, 1977 (Scheider et al., 1978).

Heavy autumn rains also cause depressed pH in runoff for a few days at a time. In one particular year of study, Jeffries¹⁷ observed as much as 25.8% of the total annual hydrogen ion runoff from small watersheds in October.

There are about 35 streams under study in the Dorset calibrated watersheds and some have results for a period of five years. The results for the Harp and Red Chalk Lake watersheds presented here are typical of the full set of observations and it can be concluded that atmospheric acid loadings are causing periodic water quality changes. The study lakes all have low alkalinities but are representative of thousands of lakes in the Precambrian area.

The summer alkalinity value of Clear Lake in McIntock Township at Dorset, was 33 $\mu\text{eq/l}$ in 1967 and only 14 $\mu\text{eq/l}$ in 1977 indicating a net loss of buffering capacity,¹² in other words, the lake is acid-stressed. This lake is only unique in that accurate historical data were available. There is no reason to doubt that many other sensitive Ontario Lakes have already shared the same fate and that many thousands more will follow in due course if no abatement action is taken.

Table 6.2 indicates the distribution of alkalinity values for various areas of the Precambrian Shield.

The number of lakes sampled in each area to date, (Table 6.2), is small in comparison to the total lakes in these areas, but based on this data it is becoming clear that a very high percentage of the lakes in the entire Precambrian Shield fall in the extremely or moderately sensitive categories.

The lakes in the extreme sensitivity category are currently acid stressed (suffer pH depression in the spring runoff) and are likely to be acidified by long range transport if current acid loadings continue. Loss of buffering capacity is cumulative, its rate and timing dependent on the rate of deposition. Once lost, there is nothing to prevent the lake from quickly acidifying. This supposition is supported by the long term observations of lake acidification in Scandinavia⁷ and the Adirondacks.²⁰

6.3.2 Ground Water

Hultberg¹⁶ has identified a number of shallow wells in Sweden which have become acidic as a result of acidic precipitation infiltrating soils with very low neutralizing capacity. The acid water has caused serious corrosion of plumbing and in some cases entire systems of copper pipes have had to be replaced after 10 to 15 years of use. The acidic wells are characterized by rock outcrops allowing surface runoff to move to sandy subsoil with minimal contact with surface soils. There is little opportunity for the neutralizing capacity of the surface soils to be utilized in neutralizing the runoff.

TABLE 6.2 SUMMARY OF THE PERCENTAGE OF LAKES IN EACH ALKALINITY CLASS BY COUNTY OR DISTRICT

Percentage of Total No. of Lakes in each Alkalinity Class						
County or District	Acidified (<u><</u> 0 $\mu\text{eq/l}$)	Extreme Sensitivity (> 0 to 39.9 $\mu\text{eq/l}$)	Moderate Sensitivity (40 to 199 $\mu\text{eq/l}$)	Low Sensitivity (200 to 499 $\mu\text{eq/l}$)	Not Sensitive (<u>></u> 500 $\mu\text{eq/l}$)	Total No. of Lakes Surveyed In County/ District
Algoma District	5	11	30	28	26	163
Bruce Co.					100	7
Cochrane Dist.		7		11	82	27
Durham Co.					100	1
Frontenac Co.				6	94	64
Grey Co.		24			100	3
Haliburton Co.			39	22	15	112
Hastings Co.			21	11	68	63
Huron Co.					100	1
Kenora Dist.			14	25	61	88
Lanark Co.					100	15
Leeds Co.			36		100	24
Lennox & & Addington Co.				12	52	25
Manitoulin Dist.	52	29	3	3	13	31
Middlesex Co.	1	30	61	2	100	1
Muskoka Dist.					6	115

...continued/

TABLE 6.2 SUMMARY OF THE PERCENTAGE OF LAKES IN EACH ALKALINITY CLASS BY COUNTY OR DISTRICT

Percentage of Total No. of Lakes in each Alkalinity Class						
County or District	Acidified (≤ 0 $\mu\text{eq/l}$)	Extreme Sensitivity (> 0 to 39.9 $\mu\text{eq/l}$)	Moderate Sensitivity (40 to 199 $\mu\text{eq/l}$)	Low Sensitivity (200 to 499 $\mu\text{eq/l}$)	Not Sensitive (> 500 $\mu\text{eq/l}$)	Total No. of Lakes Surveyed In County/ District
Nipissing Dist.		9	75	13	3	75
Northumber- land Co.					100	1
Ontario Co.					100	5
Parry Sound Dist.	5	20	64	10	1	107
Peel Co.					100	1
Peterborough Co.		4	16	6	74	49
Prince Edward Co.					100	3
Rainy River Dist.		3	64	19	14	99
Renfrew Co.			8	32	60	50
Simcoe Co.					100	7
Stormont Co.					100	1
Sudbury Dist.	24	29	23	12	12	210
Thunder Bay Dist.	1	2	25	27	45	136
Timiskaming Dist.	13		7	27	53	30
Victoria Co.					100	11
York Co.					100	2
						1,527

Many wells in the Precambrian area of North America servicing seasonal cottages and permanent homes are located in similar geological conditions so the potential for acidification of ground water exists. The first field surveys were carried out in 1980 in the Muskoka-Haliburton area of Ontario. A total of 85 ground water samples were analyzed for pH. Sampling was done in July along a line between McTier and Bancroft, and in October along a line between Parry Sound and Barry's Bay. Ground water was sampled from shallow springs and at various depths in wells obtaining water from both bedrock and overburden formations.

The sampling results indicated the acid shock effects of the spring snow melt on ground water sources. Eleven of the 85 samples had pH values less than 6.0, with the lowest value being 5.2. Subsequent sampling (summer, fall) of five of the low pH values resulted in only one sample still having a pH of less than 6.0.

6.3.3 Fisheries Damage

Fish population damage is a major concern as it represents loss to the sport fishing industry and serious disruption of the biological food chain since so many birds and mammals depend on fish for food. Complete loss of fish tends to be regarded as the definition of a "dead" lake.

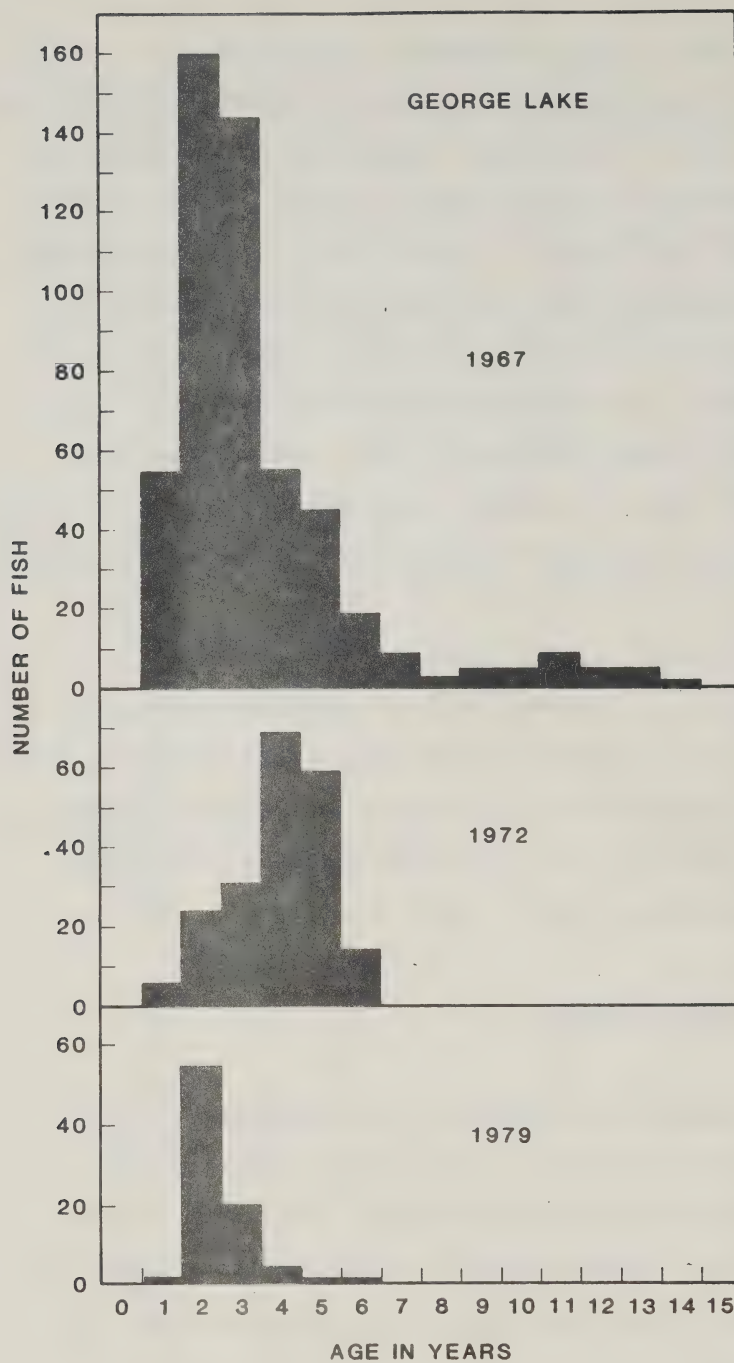


Figure 6.4 Changes in the age composition of the White Sucker in George Lake, Ontario. See text for references.

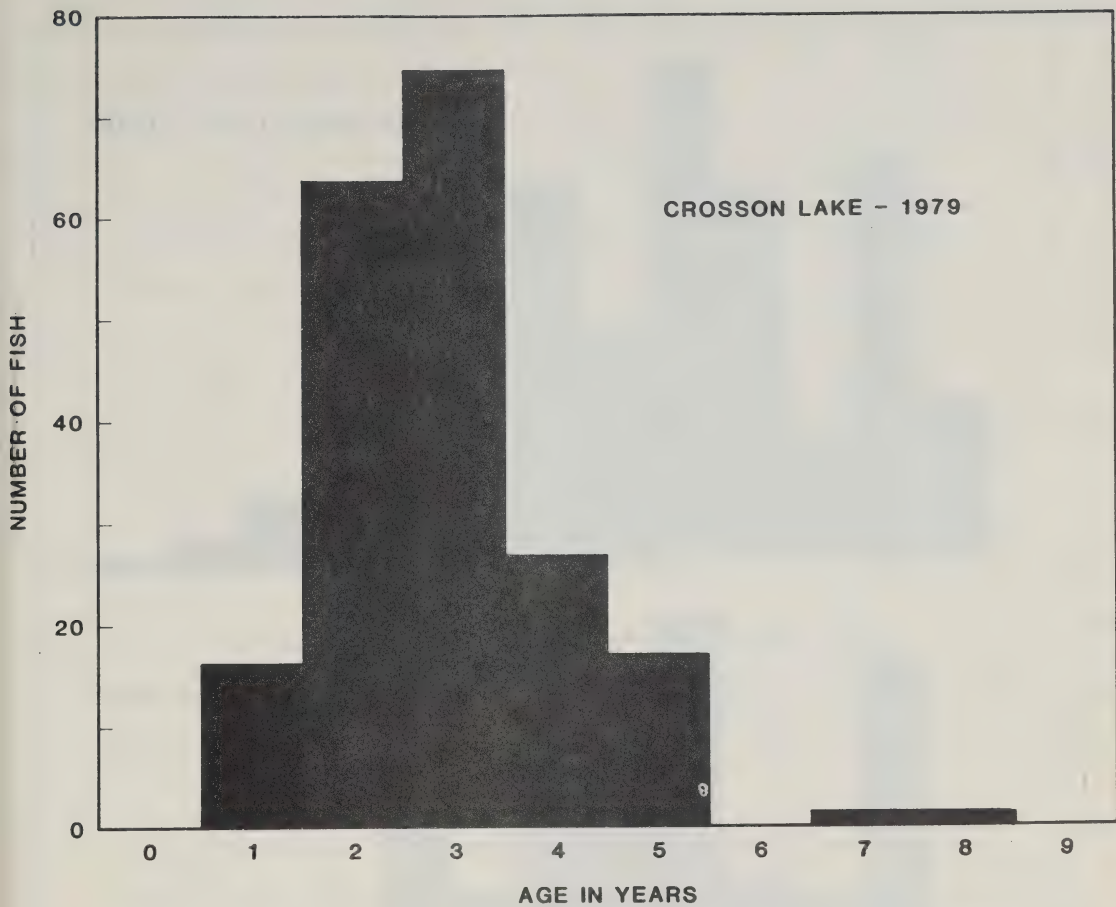


Figure 6.5 Age composition of the White Sucker in Crosson Lake.

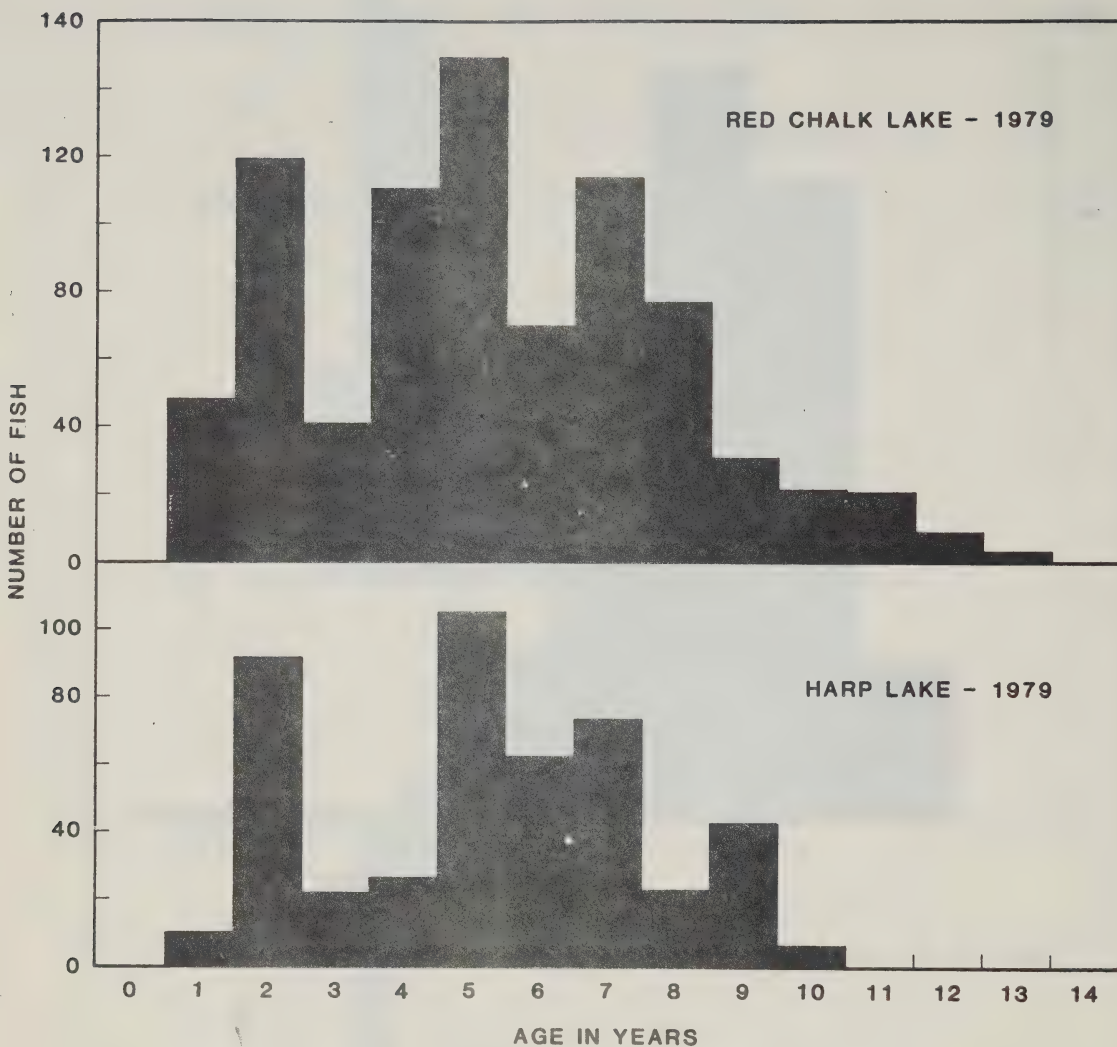


Figure 6.6 Age composition of White Sucker for Harp and Red Chalk Lake, 1979.

When the buffering capacity of a lake has been reduced and the summer pH drops below about 5.5 the fish population declines rapidly. Virtually no fish survive for long at pH below 4.5³.

A small number of lakes at Dorset have been subjected to intensive fish population measurements and several observations are relevant.

Four study lakes (calibrated watersheds) have average pH values of 5.7 (Plastic), 6.0 (Crosson), 6.6 (Red Chalk) and 6.6 (Harp). Corresponding alkalinities are 6, 61, 92 and 96 $\mu\text{eq/l}$ respectively.

Plastic Lake has experienced fish kills during snow melt when the pH has been as low as 4.7 (Harvey, pers. comm.).

Figure 6.4 shows the age distribution of white suckers in George Lake near Sudbury during a 13 year period while the lake was becoming acidic.^{2,5,14} There is a distinct shift toward a younger average age and this is believed to be a characteristic response to lake acidification. Figures 6.5 and 6.6 show the age distribution of white suckers in Crosson and Red Chalk Lakes in 1979. The shift toward a younger average age in Crosson Lake suggests damage by acidification - in this case the spring pH depression being the main manifestation of the phenomenon.

White suckers are an important "test species" since they are not subject to fishing pressure and therefore, any changes in population are due to environmental effects. Figure 6.7 shows the age composition for white suckers in Chub Lake with the year 4 age class missing. This is also a characteristic of lakes subject to acidification damage. (Harvey, pers. comm).

These observations provide strong evidence that the fisheries are beginning to suffer under the present acid loading conditions. It is reasonable to assume that similar changes are taking place in the many thousands of lakes with similar alkalinities which are likely experiencing similar water quality effects.

6.3.4 Mercury in Fish

Since elemental, metallic mercury can exist in the gas phase at ordinary air temperatures it has become ubiquitous in the environment. Large quantities of mercury pass between the earth and the atmosphere by natural cycling processes which have been going on for millions of years. Therefore, the mere presence of mercury in any compartment of the environment does not necessarily imply any human influence.

Man's propensity to utilize the atmosphere for the disposal of wastes influences the natural mercury cycle

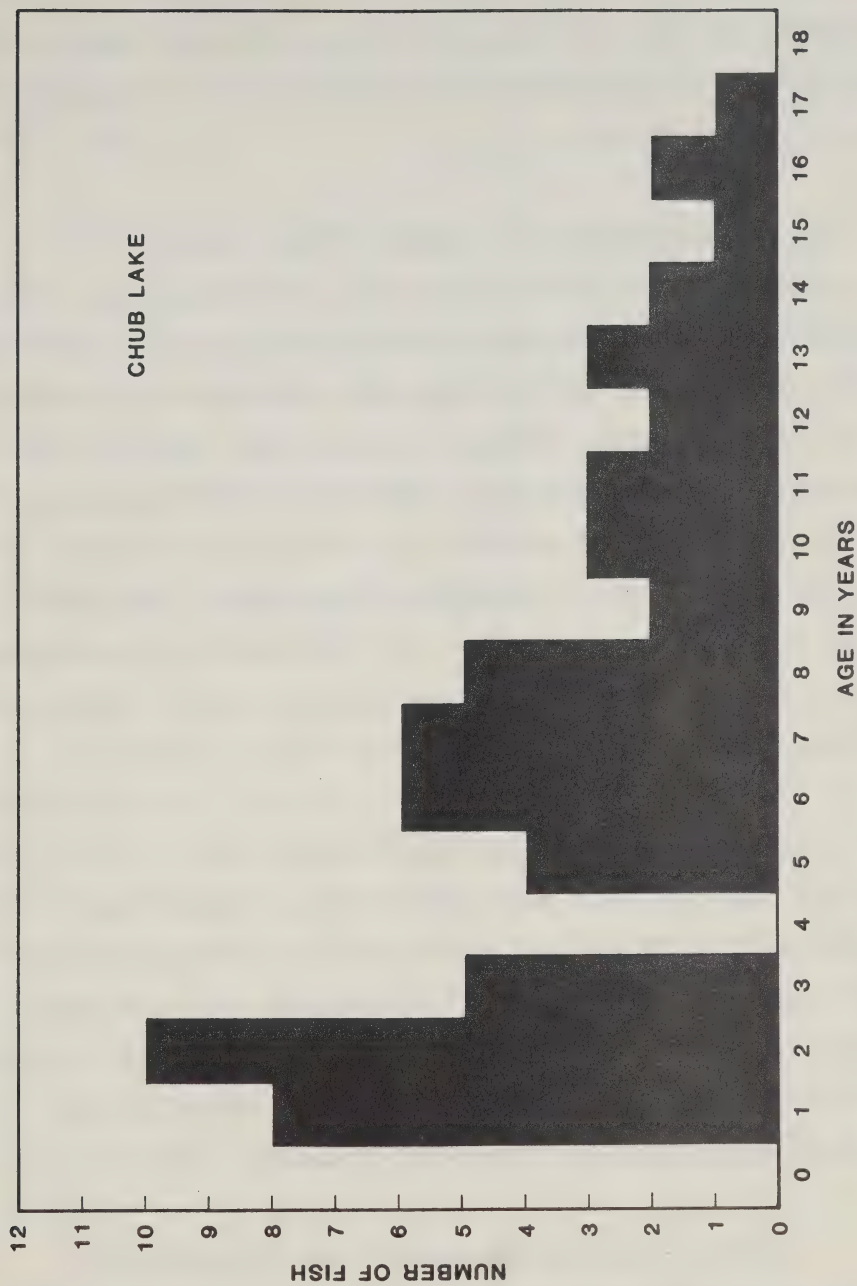


Figure 6.7 Age composition of White Sucker for Chub Lake 1979.

in two ways. Firstly, man's activities directly increase the total amount of mercury entering the atmosphere. Secondly, the amount of mercury in fish and other aquatic organisms is increased due to the acidification of surface waters by acid deposition.

Regarding the first influence, it has been estimated that on a global scale human activities have increased the mercury emissions to the atmosphere by 27%¹⁸, but it is not known how this increase influences the global mercury cycle. Within eastern North America, however, the situation is quite different. Man-made mercury discharges to the atmosphere from the U.S. states bordering on the Great Lakes are 170% of the natural atmospheric loading.¹⁸ States farther south which may still influence the Precambrian area by long range transport have similar man-made atmospheric discharges.

Coal contains on average about 60 ng/g of mercury¹¹ and up to 97% may be emitted from stacks upon combustion.⁶ The mean residence time in the atmosphere has been estimated to be 11 days.¹⁸ Therefore, there is plenty of time for long range transport prior to deposition. These points are of particular concern regarding any policy to increase the use of coal as an energy source.

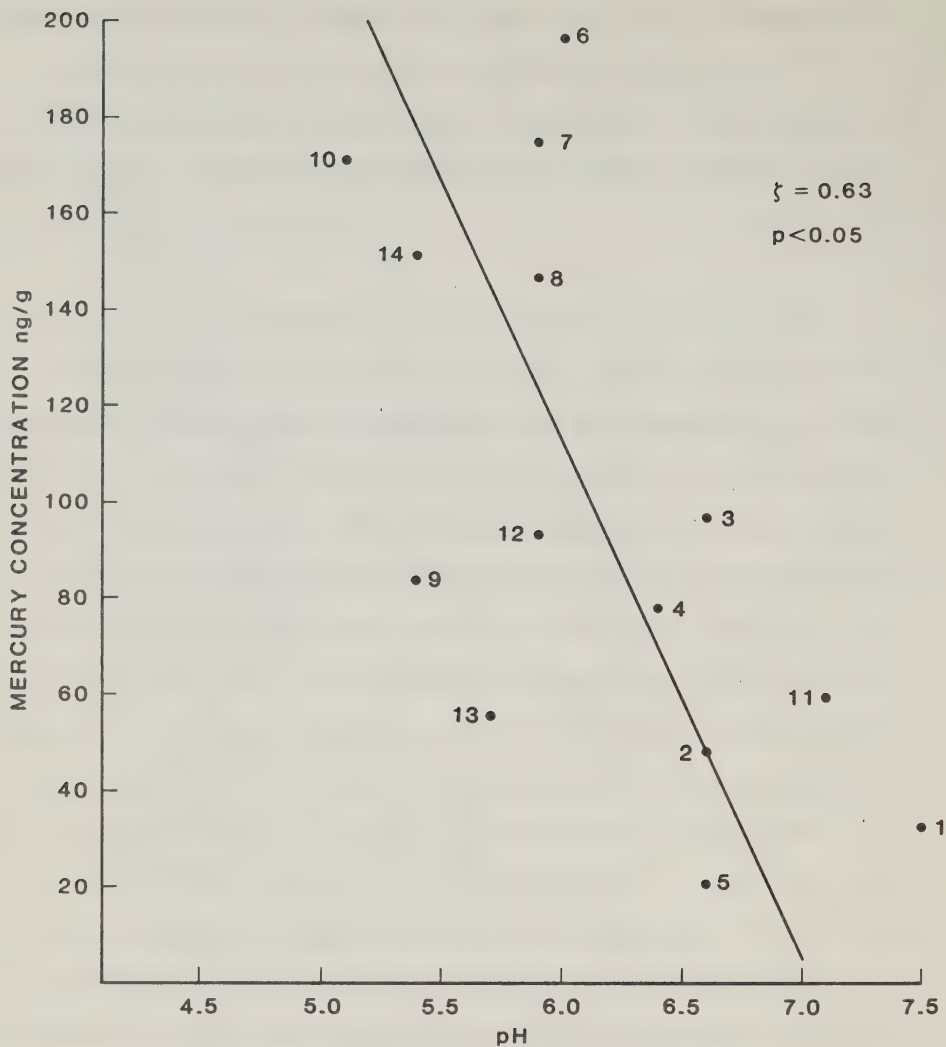
If all other factors were equal, one could expect such large increases in atmospheric emissions to increase

the deposition rate and hence, the concentrations of mercury in living organisms. However, while logical, increased deposition has not yet been fully substantiated as atmospheric studies on mercury have only been carried out in a preliminary way to date.

Regarding the second factor influencing the natural mercury cycle, that is, acidification of surface waters, it has already been demonstrated as cause for concern. Acidification of lakes takes place over a time period measured in years or even decades. During this time there will still be fish in the water although the average pH of the water will be slowly declining. It has been shown that the lower pH conditions tend to cause increases in the mercury concentrations in fish.^{14,8,1}

One possible explanation of this is as follows: methyl mercury is generally in the dimethyl form which is a gas at room temperature with low solubility in water. It can move through the environment without much effect on biological systems. Under acidic conditions, the dimethyl mercury loses one methyl group and becomes ionic monomethyl mercury which is much more soluble in water and apparently more readily taken up by fish and other aquatic life. The methyl mercury form is extremely toxic to most life forms.

The result is, that over a long period of time, lakes and rivers subjected to acid stress will still have



1978 DATA

LAKE #, NAME	TWP.	LAKE #, NAME	TWP.
1 DUCK LAKE	MINDEN	8 DICKIE LAKE	McLEAN
2 LITTLE CLEAR LAKE	SINCLAIR	9 LEONARD LAKE	MONCK
3 HARP LAKE	SINCLAIR	10 HENEY LAKE	McLEAN
4 BIGWIND LAKE	OAKLEY	11 CRANBERRY LAKE	GUILFORD
5 NELSON LAKE	BOWELL	12 HEALEY LAKE	McCAULEY
6 CHUB LAKE	RIDOUT	13 CLEAR LAKE	STANHOPE
7 CROSSON LAKE	OAKLEY	14 FAWN LAKE	McCAULEY

Figure 6.8 Mercury concentrations in yearling yellow perch and epilimnetic pH relationships (Suns et al., 1980).

some fish but the mercury concentrations in those fish will increase. Birds and animals which eat fish as a major part of their diet will ingest quantities of mercury which may well threaten their health and survival.

The fisheries within Ontario are the basic resource for a sport fishing industry valued at hundreds of millions of dollars per year. While in the long-term, acidification of lakes poses a threat to the industry, in the short-term, mercury in fish could lead to further restriction on human consumption of the fish with consequential economic loss to the industry.

Suns²⁴ has been sampling young-of-the-year and yearling fish for contaminant studies. This approach reduces some of the variables since the fish are uniform with respect to age and diet. The data, Figure 6.8, demonstrate increased mercury concentrations in fish from lakes with lower pH in the Haliburton area of Ontario. It was further shown that for lakes with similar pH, the mercury was higher in fish from lakes with a higher ratio of drainage area/lake volume. This result implies that the quantity of mercury from either direct atmospheric deposition or watershed leaching is influencing the mercury concentrations in fish. The surveys have not been carried out long enough to establish any trends with time.

In 1980, the survey was extended to include adult bass which are an important component of the sport fishery.

Bass from six of the nine lakes studied had average mercury concentrations above the Canadian guideline for unlimited human consumption of 500 ng/g. In one lake, the U.S. guideline of 1000 ng/g was exceeded.

6.3.5 Leaching of Aluminum

Acidic precipitation has the potential of increasing the leaching rate of material from the watershed. Aluminum is a major constituent of the bedrock material in the Precambrian area and it tends to be dissolved by acidic runoff. Scheider²² reported an average total aluminum concentration of 49 µg/l for the study lakes at Dorset. Concentrations in streams are typically up to 200 - 300 µg/l with some measurements exceeding 500 µg/l particularly in the spring runoff (Scheider, pers. comm.).

Laboratory experiments have shown that survival of brook trout was reduced to less than 50% after 14 days at aluminum concentrations of 420 and 480 µg/l at pH values of 5.2 and 4.4 respectively.¹³

It appears that the pH and aluminum concentrations being observed in the Dorset study lakes during spring snow melt fall within the ranges which laboratory experiments have shown to be lethal to fish. It is quite possible that the observed fish kills and apparently altered age distribution of white suckers are due to the combination of pH and aluminum.

6.3.6 Algal Growth

The algae growing in acid stressed and acidic lakes undergo species changes which are detrimental to the recreational use of the lakes and which pose a threat to the habitat of some aquatic organisms. For example, lakes with reduced pH support a proliferation of algae attached to the bottom. The technical term is benthic filamentous algae. This algae can coat gravel fish spawning beds making successful spawning impossible. Significant growths of these algae have been observed in Muskoka-Haliburton lakes such as Plastic, Chub and Leonard.

Another observed change, detrimental to recreational activities, is the appearance of an alga called Chrysochromulina breviturrita Nich. which is characterized by a severe "rotten cabbage" or "garbage dump" odour which has caused lakes to be unsuitable for swimming. The alga has reached problem concentrations in four lakes in Ontario and one in New Hampshire in the past three years. Crosson Lake has experienced the problem. Dickie Lake had an extreme problem in 1979 and it has had cottagers there for over 20 years with no previous observations of the odour.¹⁹ The odour is so bad that residents would likely have remembered had it ever occurred before.

The alga has now been identified at various population sizes in over 40 lakes in Ontario, most of which have low pH.

6.3.7 Amphibians

In the Muskoka-Haliburton area, densities of several species of amphibians decrease with increasing acidity of their habitat. Acidic lakes and streams support a smaller breeding population of spring peepers (Hyla crucifer) than more neutral habitats. Deciduous woodland ponds are the typical breeding habitats for Ambystoma salamanders. However, such ponds have been observed in Muskoka-Haliburton to be very acidic with pH's as low as 4.3. These acidic ponds are now seldom used as breeding sites and thus represent a loss of habitat for this species. The hatching success of any eggs laid in these habitats is low.⁹

6.4 Summary of Water Quality Effects

The current acid loadings to parts of the Precambrian rock areas of Ontario, and in particular the important recreational areas of Muskoka and Haliburton, are causing some lakes and rivers to have low pH values for a few weeks during spring melt and for several hours or days during heavy summer and autumn rains. These lakes are regarded as acid-stressed.

From 60% to 90% of the lakes in the Parry Sound Muskoka-Haliburton area (approximately 12,000 to 18,000 lakes) are sensitive to damage by the short term low pH conditions and may also be acidified over a longer period of time to the point where no fish survive.

Intensive studies on the biological effects of the observed water quality damage are being carried out in a small number of lakes. Fish kills have been observed in the most sensitive study lake. The white sucker population appears to be damaged in a less sensitive study lake. A complete year class of fish is missing in a third sensitive study lake. The pH and aluminum conditions may be the cause of the observed fishery conditions. Low pH and coincident high concentrations of aluminum have been observed in streams at values which laboratory experiments have shown to be lethal for fish.

Mercury concentrations are elevated in fish from lakes with pH below about 6.0. There is reason to suspect that increased man-made atmospheric emissions of mercury from coal burning, coupled with acidification of precipitation and surface waters, will lead to higher mercury concentrations in fish and to more lakes being affected.

Any loss or modification of the quality of sport fish is a major concern to the sport fishing industry valued at hundreds of millions of dollars per year in Ontario.

Several study lakes have been observed to have a proliferation of algae attached to the bottom. This algae poses a threat to fish spawning grounds.

Some lakes with low pH have experienced problems with a foul smelling alga which restricts the recreational

use of the lakes. The occurrence of large amounts of this alga appears to be a recent phenomenon and appears to be related to acid-induced low pH conditions in lakes.

The evidence of effects of acid deposition on the aquatic ecosystem suggests that continued deposition, particularly in the absence of sufficient buffering capacity, causes damages and losses, which in the long run, are irreversible.

The acid stressed lakes under study are showing a number of examples of biological damage. It is nearly certain that similar damage is being experienced by the thousands of lakes with similar alkalinity values and hence, they are experiencing similar water quality effects of acidic runoff in the spring and during heavy rains.

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SIGNIFICANCE TO ONTARIO OF THE EMISSIONS
FROM THE 20 POWER PLANTS

7.1 How the Contributions Are Assessed

Information about the twenty U.S. power plants included in these proceedings is listed in Table 7.1 including: the SO₂ emissions allowed under the current (1979) SIP regulations*, the proposed increase above the 1979 regulations, and an estimate of the actual 1979 SO₂ emissions.¹

This chapter uses this information to assess the significance of the proposed SIP changes to sensitive areas of Ontario. The assessment is based on the Ontario Ministry of Environment statistical model² for the long-term, long-range transport of sulphur pollution. The model estimates of sulphur, deposited during precipitation (i.e. wet deposition of sulphur), have been verified using documented experimental results from several monitoring networks for 1977-78. It was found that all model predictions were within a factor of two of the observed values and over 60% of the model estimates were within 35% of the expected values.

*For Docket No. 5A-79-1 we use August 27, 1976 SIP emission limits for the Eastlake and Avon Lake Plants (i.e. 1.43 and 1.15 lbs. SO₂/MBTU respectively) as the base and oppose any relaxation thereof.

Table 7.1: U.S. Coal-Burning Power Plants Proposing an Increase
in their SO₂ Emission Limits

NOTE: All figures are in thousands of metric tons.

	<u>STATE</u>	Amount Allowable Under 1979 Regulation	Proposed Increase In Emissions Above Regulation	Proposed Total Emissions	Estimated 1979 SO ₂ Emissions
Power Plant					
<u>ILLINOIS</u>					
1)	Baldwin	228.7	54.4	283.1	257.9
<u>INDIANA</u>					
2)	Clifty Creek	46.2	174.5	220.7	263.7
3)	Tanners Creek	26.1	116.6	142.7	85.2
4)	Michigan City	17.0	84.1	101.1	62.4
5)	Culley	12.5	50.4	62.9	61.3
6)	Bailly	13.9	46.6	60.5	58.0
7)	Stout, Elmer W.	17.6	72.2	89.8	44.2
8)	Warrick	4.3	111.7	116.0	20.2
9)	Mitchell, Dean H.	13.6	62.2	75.8	19.2
<u>MICHIGAN</u>					
10)	Cobb	40.3	20.2	60.5	69.3
11)	Campbell	39.2	19.5	58.7	57.0
<u>OHIO</u>					
12)	Muskingham	235.0	150.5	385.5	340.2
13)	Cardinal	214.1	68.6	282.7	140.8
14)	Beckjord	136.0	9.2	145.2	99.7
15)	Poston	16.3	16.3	32.6	29.1
16)	Bayshore	19.3	16.2	35.5	23.7
17)	Avon Lake	26.0	111.4	137.4	98.0
18)	Eastlake	36.5	131.4	167.9	137.4
<u>TENNESEE</u>					
19)	Kingston	51.0	90.2	141.2	87.2
<u>WEST VIRGINIA</u>					
20)	Kammer	63.6	157.3	220.8	136.8
<u>TOTAL</u>		<u>1257.2</u>	<u>1563.5</u>	<u>2820.7</u>	<u>2091.3</u>

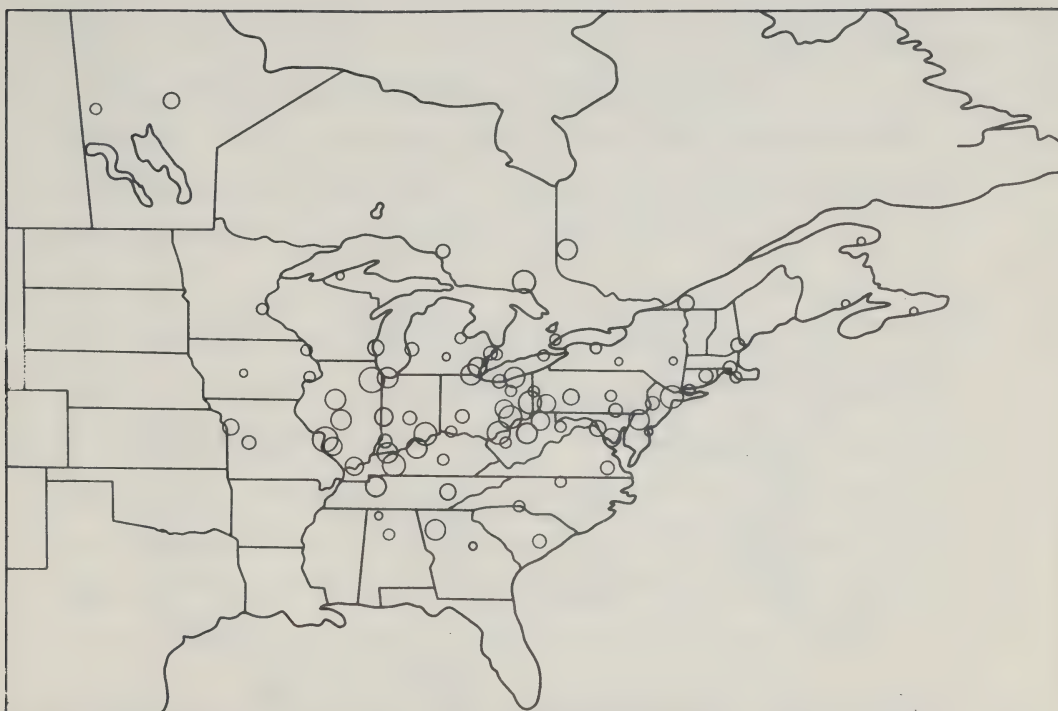


Figure 7.1 Distribution and relative magnitude of the emission inventory for 1979.

LEGEND

Circled area represents source strength

- 100 K TONNES/YR
- 200 K TONNES/YR
- 300 K TONNES/YR
- 400 K TONNES/YR
- 500 K TONNES/YR
- 600 K TONNES/YR
- 700 K TONNES/YR
- 800 K TONNES/YR

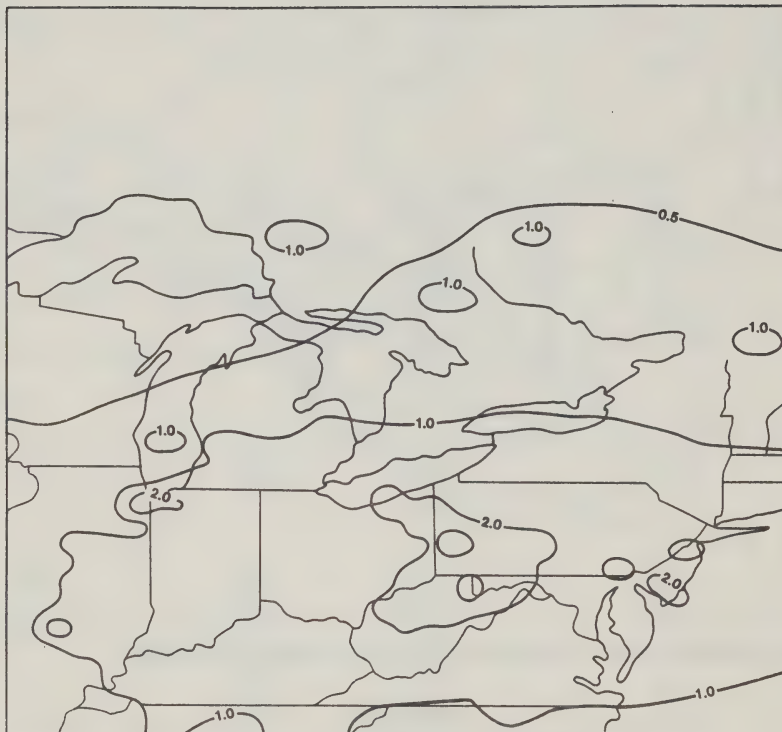


Figure 7.2 Total annual wet deposition of sulphur ($\text{gm/m}^2/\text{yr}$) due to all SO_2 emissions shown in Figure 7.1 and including a background deposition of $0.2 \text{ g/m}^2/\text{yr}$ to account for sources not in the inventory and biogenic sulphur emissions.

Acidity in precipitation is caused by the hydrogen (H^+) ion and is due primarily to sulphuric acid (H_2SO_4) nitric acid (HNO_3) and ammonium bisulphate (NH_4HSO_4). Measurements in eastern North America have shown a high correlation between the concentrations of the H^+ ions and $SO_4^{=}$ ions present in precipitation.³ Therefore, while this model deals only with the amount of wet deposition of sulphur, it can be inferred to be also a good indication of the precipitation acidity.

The model needs an inventory of SO_2 sources as input. The distribution and relative magnitude of points in the SO_2 emission inventory for 1979 are illustrated in Figure 7.1. Figure 7.2 shows the calculated total annual deposition of sulphur during precipitation from these sources. The total annual wet deposition rate is highest in the industrial regions of Ohio, West Virginia and Pennsylvania where it exceeds $3 \text{ g/m}^2/\text{yr}$. This deposition rate includes a background contribution rate of $0.2 \text{ g/m}^2/\text{yr}$ which has been added to the model estimate to incorporate the effects of sources not in the model inventory, and to account for biogenic sulphur emissions.²

7.2 Actual 1979 Emissions and Their Contributions to Ontario's Wet Deposition

Figure 7.3 shows the location of the 20 power plants proposing an increase in their SO_2 emission

limits. The area of each point source is proportional to the magnitude of the actual 1979 SO₂ emission value. The contribution to wet deposition due to the actual 1979 emissions of these power plants as compared to the total annual wet deposition of sulphur from all sources is displayed in Figure 7.4, as a percentage. The results show that:

- . The largest contribution from these plants occurred in the southern portions of Illinois, Indiana and Ohio, near large emitters.
- . In the environmentally sensitive Ontario regions of Muskoka-Haliburton and Algoma, these plants contributed between 2.5 - 6.0% of the sulphur deposited in precipitation.
- . Column 1 of Table 7.2 summarizes the contribution of the 20 plants to the total wet deposition in these and other sensitive areas in the Great Lakes region.

7.3 Contributions Occurring if the SIP's Had Been Obeyed

The contributions which would have occurred if the 1979 emissions from these 20 plants had been held to their legal limits (as prescribed by various current SIP's) will now be discussed. Figure 7.5 shows these contributions, and Figure 7.6 shows the percentage difference between actual, and SIP-limited cases. The differences are calculated as follows. Wet deposition values from the case using (a) the 1979 SIP-limited emissions from the 20 plants and (b) actual 1979 emissions from the rest of the sources in the airshed are subtracted from the wet deposition values computed in the case where all plants emitted at their

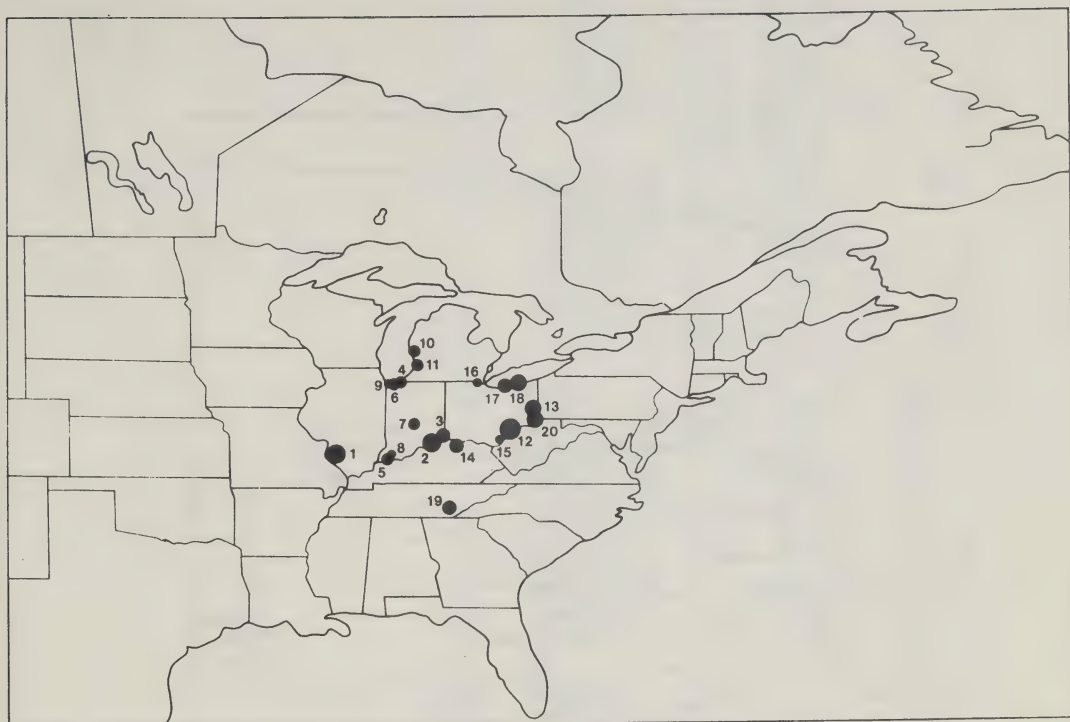


Figure 7.3 Distribution and relative magnitude of the 1979 SO₂ emissions of the U. S. power plants proposing an increase in their regulated SO₂ emission limits.

LEGEND

Circled area represents source strength

- 100 K TONNES/YR
- 200 K TONNES/YR
- 300 K TONNES/YR
- 400 K TONNES/YR
- 500 K TONNES/YR
- 600 K TONNES/YR

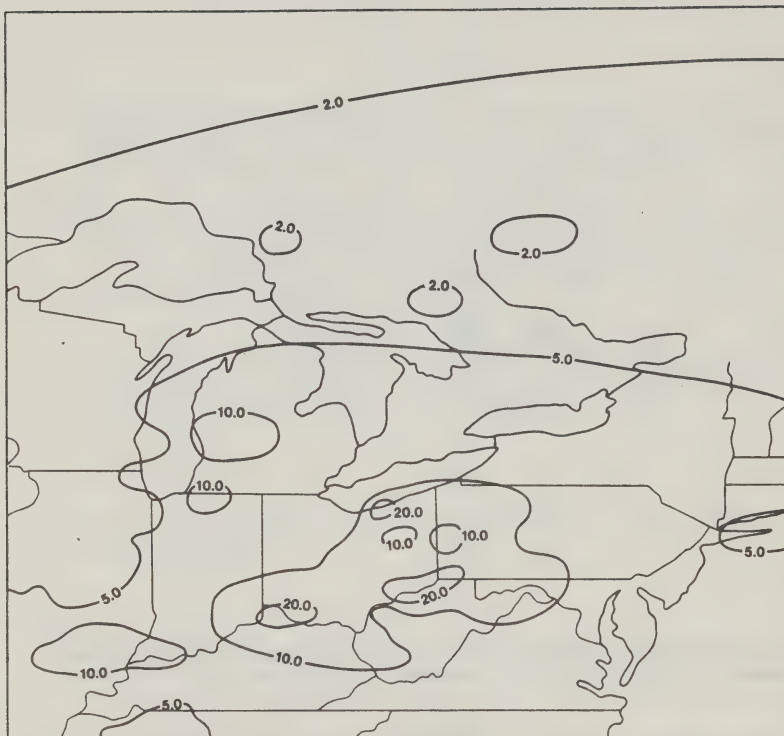


Figure 7.4 Relative contribution (in percent) of the 1979 SO_2 emission of the of the 20 U. S. power plants being studied to the total annual wet deposition of sulphur.

Table 7.2: Contributions of Wet Sulphur Deposition From 20 U.S. Power Plants Under Various Emission Cases to Environmentally Sensitive Areas in Canada and the U.S.

Note: Each column presents data connected with plants' emissions, as described. In all cases, the data are expressed as wet deposition percentages, with the normalizing factor being the total wet deposition occurring in 1979 due to actual emissions from all sources.

Note: Model predictions have been verified to be accurate within a factor of 2 with 60% of the estimates being within 35% of expected values. The range of values given in the text are derived from the figures below.

Sensitive Region	Amount due to actual 1979 emissions	Decrease occurring if 1979 actual emissions were reduced to 1979 SIP maximums.	Increase occurring if emissions rise from 1979 SIP maximum to proposed maximum.	Increase occurring if emissions rise from actual 1979 levels to proposed new limits.	Amount due to emissions if they are held at 1979 SIP limits (Column 1 minus Column 2)	Amount due to emissions if they rise to proposed new limits (Column 1 plus Column 4)
Muskoka-Haliburton, Ontario	4.5	2.0	3.4	1.4	2.5	5.9
Algoma, Ont.	3.0	1.3	2.2	0.9	1.7	3.9
Lakehead, Ont.	1.9	0.8	1.4	0.7	1.1	2.6
Val D'or, Que.	2.7	1.1	2.0	0.8	1.6	3.5
Adirondacks, N.Y.	5.5	2.3	4.3	1.9	3.2	7.4
West Pennsylvania	11.4	3.4	8.5	5.0	8.0	16.5

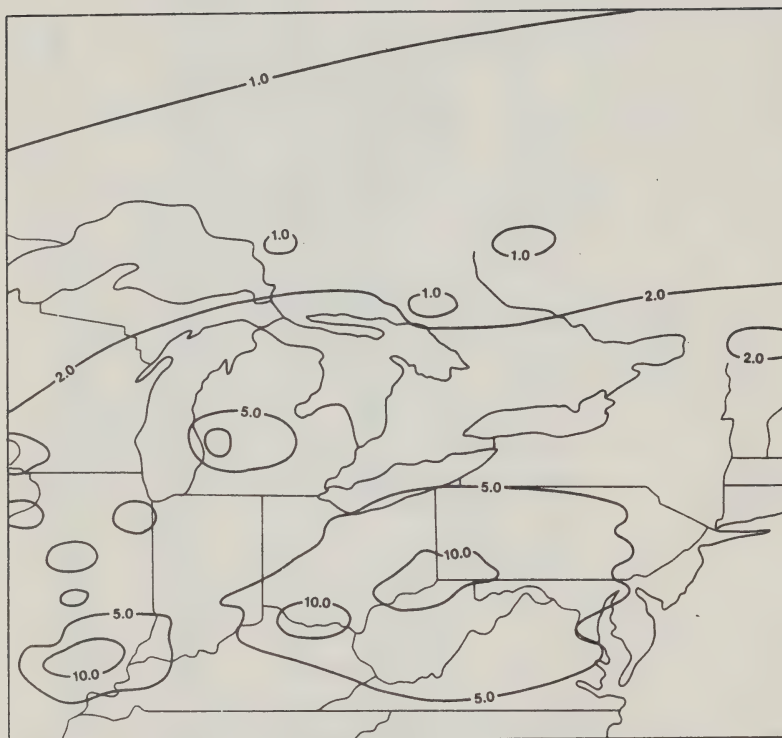


Figure 7.5 Percentage contribution of the 20 U. S. power plants being studied to the total annual wet deposition of sulphur if they emitted the amount of SO_2 allowable under 1979 regulations.

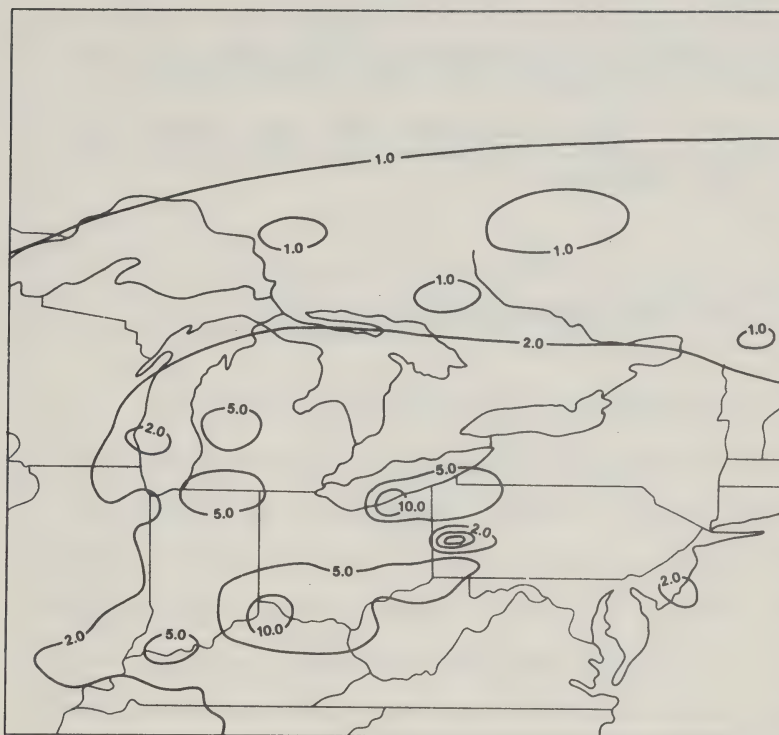


Figure 7.6 Difference between the contribution of the 1979 SO₂ emissions and the contribution of the 1979 regulation emissions of the 20 power plants under consideration (1979 Emissions-1979 Regulations), shown as a percentage of the 1979 total wet deposition of sulphur.

actual 1979 levels. These differences are divided by the values of the latter cases to form a percentage. The results show that:

- . In Muskoka-Haliburton, the contribution drops by 1.5 - 2.5% when the 20 plants obey the current SIP's.
- . In Algoma, the contribution drops by 0.7 - 1.7% when the 20 plants obey the current SIP's.
- . Column 2, Table 7.2 summarizes this analysis for other sensitive regions of the northeastern part of the continent.

7.4 Contributions Which Will Occur if Emissions Rise to the New Proposed Limits

Figure 7.7 shows the percentage contribution of the wet sulphur deposition from these 20 plants which will occur if these plants increase their emissions to the new proposed SIP limits, while all other sources emit at their actual 1979 levels. Figure 7.8 shows the difference between two cases; i.e. the one involving emissions occurring at the new proposed limit levels and the one involving actual 1979 emissions. Finally, Figure 7.9 shows the difference between two other cases; i.e. the one involving emissions at levels occurring if the current SIP's are obeyed and that occurring at the proposed limited levels. The results show that:

In Muskoka, emissions from the 20 plants occurring at the proposed new limits will account for 4.5 - 8.5% of the total from all sources. This is 0.8 - 1.8% more than the actual 1979 emissions case, and 2.0 - 4.0% more than the case where current SIP limits are obeyed.

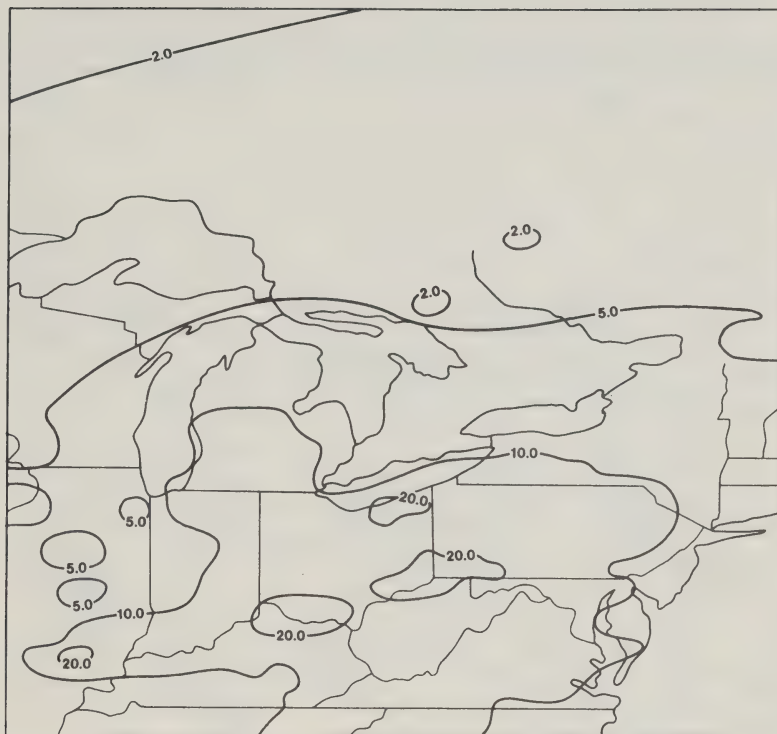


Figure 7.7 Percentage contribution of the 20 power plants under consideration to the total annual wet deposition of sulphur if their SO_2 emission is equal to the proposed new limits.

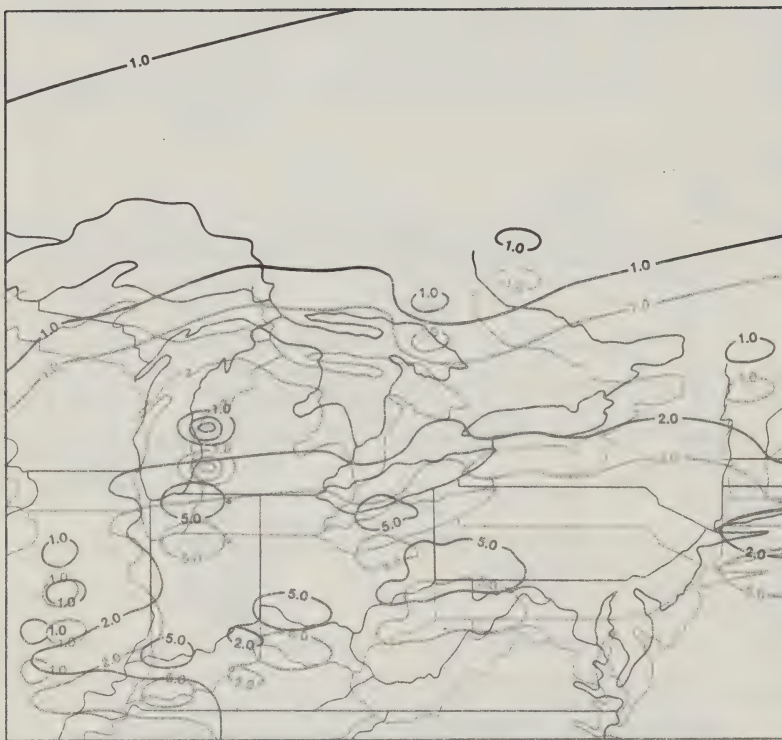


Figure 7.8 Difference in contribution between the case in which emissions of the 20 plants reached the proposed limits and the case for the actual 1979 emissions. Results expressed as percent of the 1979 sulphur deposition.

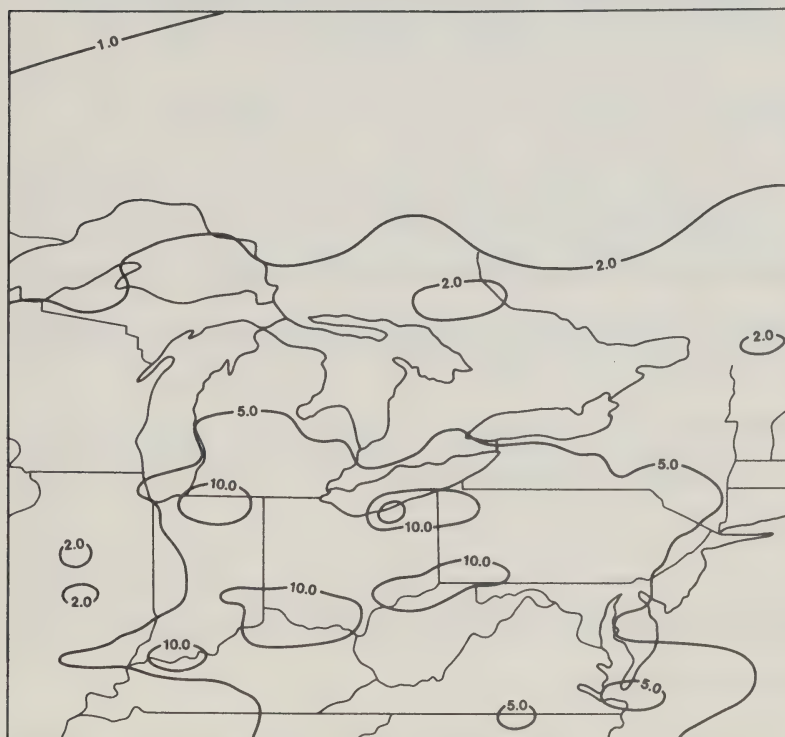


Figure 7.9 The difference in contribution between the case in which the emissions from the plants reached the proposed limits and for the case in which the plants emissions met SIP 1979 Regulation limits. Results expressed as a per cent of the 1979 sulphur deposition.

- Similarly, in Algoma the same proposed emissions levels account for 3.3 - 5.8% of the total due to all sources. This is 0.5 - 1.5% more than the actual 1979 emissions case, and 1.6 - 2.8% more than the case of obeying the current SIP limits.
- Columns 3 and 4 of Table 7.2 list the analysis results for other sensitive receptor areas.
- Columns 5 and 6 of Table 7.2 show the percent contribution to those areas if the new limits were reached by the 20 sources, and in comparison, the contributions arising from obeying the current SIP's.

7.5 Summary

It is clear from this discussion that the contribution to Ontario's environmentally sensitive areas by the 20 plants in question will more than double if emissions rise along with the SIP limits. The contributions in the case of the new limits will form a significant part of the damage to Ontario's environment.

It is also clear that enforcement of the original SIP's by EPA would reduce the deposition in Ontario and help reduce ecological damage.

While all of this analysis has been performed for wet deposition, results would be very similar for dry deposition, because the spatial distribution of dry deposition is similar to that of wet deposition, and the amounts of wet and dry deposition are usually similar.^{4,5,6} The dry deposition component can be modelled, but the estimates cannot be verified by field measurements at the present time.

REFERENCES - CHAPTER 7

1. The 1979 SO₂ estimates are based on the information contained in
 - a) Cost & Quality of Fuels for Electric Utility Plants-1979. Energy Data Report. FPC. Form No. 423. DOE/EIA-0191 (79), June, 1980.
 - b) Federal Power Commission, Form F "Monthly Power Plant Report" (F.E.R.C. Form No. 4), January - December, 1979.
 - c) AP-42 Compilation of Air Pollutant Emission Factors.
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ONTARIO'S ACTIVITIES TO REDUCE SO₂ EMISSIONS

It is the objective of the Ontario government to reduce acid deposition as far as possible. To this end, Ontario is protecting its environment and that of its neighbours by reducing its own SO₂ emissions, as well as pressing for a reduction from sources in neighbouring provinces and states.

8.1 Cutbacks of Sources Within Ontario

8.1.1 INCO Ltd. Operations, Sudbury

INCO's Sudbury operations have reduced emissions from approximately 2.0 million metric tons per year in 1969 to a maximum of 1.2 million metric tons per year in early 1978.

Between mid-1978 and early 1980, INCO was under a Control Order limiting emissions of SO₂ to 1.2 million metric tons per year.

In May 1980, Ontario re-evaluated the 1978 control program based on the need to provide greater controls on SO₂ emissions in order to reduce acid deposition. Consequently, the Control Order was amended and a Regulation¹ issued (see

Publications Under The Regulations Act

September 20th, 1980

THE ENVIRONMENTAL PROTECTION ACT, 1971

O. Reg. 712/80.

Copper Cliff Smelter Complex

Made - August 27th, 1980

Filed - September 2nd, 1980

R.O.C. 419/80

Copy of an Order-in-Council approved by Her Honour the Lieutenant Governor, dated the 27th day of August, A.D. 1980.

The Committee of Council have had under consideration the report of the Honourable the Minister of the Environment, wherein he states that,

WHEREAS acidic precipitation adversely affects the natural environment, including the lakes and rivers, of the Province of Ontario;

WHEREAS sulphur dioxide emitted from non-ferrous smelting operations is one of the most significant Ontario contributors to the acidic precipitation phenomenon;

WHEREAS Inco Limited's Copper Cliff Smelter Complex in The Regional Municipality of Sudbury is the major source in Ontario of sulphur dioxide emissions and thus contributes to the level of acidic precipitation in Ontario;

WHEREAS questions have arisen regarding particular limits to be placed on the total amount of sulphur dioxide emitted from the Copper Cliff Smelter Complex;

WHEREAS the particular limits in the appended Regulation have been considered by the Executive Council and found to be appropriate;

The Honourable the Minister of the Environment therefore recommends that the appended Regulation be made under *The Environmental Protection Act, 1971*, to protect the natural environment of Ontario and to remove, at the earliest possible time, any uncertainty as to the interim limits which emissions from the Copper Cliff Smelter Complex will be required to meet while studies are going on to determine whether or not any lower limits should be imposed.

The Committee of Council concur in the recommendation of the Honourable the Minister of the Environment and advise that the same be acted on.

REGULATION MADE UNDER THE ENVIRONMENTAL PROTECTION ACT, 1971

COPPER CLIFF SMELTER COMPLEX

1. This Regulation applies to Inco Limited and to emissions of sulphur dioxide from the Copper Cliff Smelter Complex of Inco Limited in The Regional Municipality of Sudbury. O. Reg. 712/80, s. 1

2. In this Regulation,

(a) "ton" means a short ton;

(b) "working day" means any day on which a process unit of the Copper Cliff Smelter Complex receives sulphur-bearing process feed material and emits any sulphur dioxide to the atmosphere. O. Reg. 712/80, s. 2.

3.—(1) Emissions during each of the four periods, each beginning on the day this Regulation is filed and respectively ending at the end of the third and fourth calendar quarters of 1980, and the first and second calendar quarters of 1981, shall not exceed, in the average, 2500 tons per working day.

(2) Emissions during each twelve-month period respectively ending at the end of the third and fourth calendar quarters of 1981, each calendar quarter of 1982 and the first three calendar quarters of 1983, shall not exceed, in the average, 2500 tons per working day.

(3) Emissions during each twelve-month period ending at the end of the fourth calendar quarter of 1983 and each calendar quarter thereafter shall not exceed, in the average, 1950 tons per working day.

(4) For purposes of subsections 1, 2 and 3, the amount of sulphur dioxide emitted on any working day for which an accurate record is kept shall be the amount so recorded and for which an accurate record is not kept shall be deemed to be the greater of,

(a) the number of tons that can be established to have been emitted; or

(b) 2500 tons for a working day up to the 31st day of December, 1982 and 1950 tons for a working day after the 31st day of December, 1982.

(5) Where, in the average, emissions exceed 2500 tons per working day with respect to any period referred to in subsection 1, there shall be deemed to be no contravention of subsection 1 in respect of that period if, in the average, emissions per working day for a

14 period of twelve months ending at the end of that period do not exceed 2500 tons. O. Reg. 712/80, s. 3.

Exhibit 8.1) which in combination with the control order required INCO to:

- (a) Limit SO₂ emissions from INCO's Copper Cliff Complex to a maximum of 833,000 metric tons per year.
- (b) Limit SO₂ emissions from INCO's Iron Ore Recovery plant so that they do not exceed an average of 83,300 metric tons per year. This average will be computed quarterly over a 12-month production period.
- (c) Submit by December 31, 1980, a report detailing the facilities and the implementation schedule necessary to limit SO₂ emissions from the INCO Copper Cliff smelter to 647,000 metric tons per year. These facilities are to be in place by December 31, 1982.
- (d) Continue the existing program designed to bring all low level emissions from the company's nickel refinery into compliance with provincial standards as set out in Ontario's Environmental Protection Act. The company must complete installation of the necessary facilities and have these in operation by December 31, 1982.

These limits are of an interim nature. When the results of investigations are known in 1983 these emission limits will be cut further to significantly lower values.

In summary, INCO's emissions have decreased under Government programs by more than 58 per cent since 1969, and they are being reduced by another 22 per cent by the end of 1982.

8.1.2. Falconbridge Nickel Mines Limited

Falconbridge Nickel Mines, Ltd. operates a smelter in Nickel Centre Ontario (near Sudbury). In 1969, their emissions of SO₂ were about 343,000 metric tons per year.

The first Falconbridge Control Order was issued on November 29, 1969. It required a 55% reduction of SO₂ emissions by December 31, 1975, or a cutback from 343,000 to 155,000 metric tons per year.

Due to the failure of the planned technology, a new Control Order was issued in 1973 allowing for emissions to be reduced to 220,000 metric tons per year by December 31, 1976 and 155,000 metric tons per year by May 31, 1979. This was further altered in July of 1977 allowing for an emission level of 280,000 metric tons per year until May 31, 1979, followed by a reduction to 155,000 metric tons per year thereafter.

By the end of 1979, Falconbridge had successfully completed the installation and commissioning of its new equipment to reduce SO₂ emissions. Their actual emissions that year were 89,000 metric tons due to abnormally low operations levels.

In summary, Falconbridge has reduced SO₂ emissions by at least 55% between 1969 and the present.

8.1.3. Ontario Hydro

Ontario Hydro's coal-fired plants together form the second largest emitter of SO₂ in the Province. (See Table 8.1). On January 26, 1981, the Ontario government issued a Regulation which places annual limits on atmospheric emissions from Hydro's power system. (Copy attached as Exhibit 8.2). As a result of this Regulation, Hydro will immediately begin implementing control activities. Due to the massive size of Hydro's generating facilities and the complexity of the steps to be taken, considerable lead time will be required before the control facilities can become fully operational.

The first part of the Regulation will limit SO₂ emissions to 390,000 metric tons per year beginning in 1985. By 1990, when most of the control measures are fully operational, the limit will drop to a permanent ceiling of 260,000 metric tons of SO₂ per year.

TABLE 8.1

SULPHUR DIOXIDE EMISSIONS FROM ONTARIO
HYDRO THERMAL GENERATING STATIONS

<u>HYDRO G.S.</u>	<u>1979 (METRIC TONS)</u>
LAMBTON Sarnia, Ontario	160,250
NANTICOKE Nanticoke, Ontario	155,080
LAKEVIEW Mississauga, Ontario	91,345
HEARN Toronto, Ontario	10,190
THUNDER BAY Thunder Bay, Ontario	10,035
LENNOX Bath, Ontario	10,010
<hr/> TOTAL	<hr/> 436,910 <hr/>

NOTE: All stations are coal-fired, except for Hearn, which operates partially on coal and partially on gas, and Lennox, which is oil-fired.

O. Reg. 72/81

THE ONTARIO GAZETTE

O. Reg. 75/81 827

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THE ENVIRONMENTAL PROTECTION
ACT

O. Reg. 73/81.

Ontario Hydro.

Made—February 17th, 1981.

Filed—February 17th, 1981.

REGULATION MADE UNDER
THE ENVIRONMENTAL PROTECTION
ACT, 1971

ONTARIO HYDRO

1. Emissions of sulphur dioxide from the fossil-fueled electric generating stations of Ontario Hydro shall not exceed, in the aggregate, 390 kilotonnes in the calendar year 1986, 1987, 1988 or 1989. O. Reg. 73/81, s. 1.

2. Emissions of sulphur dioxide from the fossil-fueled electric generating stations of Ontario Hydro shall not exceed, in the aggregate, 260 kilotonnes in any calendar year after 1989. O. Reg. 73/81, s. 2.

3. Emissions of nitric oxide from the fossil-fueled electric generating stations of Ontario Hydro shall not exceed, in the aggregate, sixty kilotonnes in the calendar year 1986, 1987, 1988 or 1989. O. Reg. 73/81, s. 3.

4. Emissions of nitric oxide from the fossil-fueled electric generating stations of Ontario Hydro shall not exceed, in the aggregate, forty kilotonnes in any calendar year after 1989. O. Reg. 73/81, s. 4.

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For comparison, Hydro's emissions were 437,000 metric tons in 1979, and 410,000 metric tons in 1980. They are projected to be about 509,000 tons in 1981. Taking the average of these figures as the measure of Hydro's current level of activity, its emissions average about 452,000 metric tons per year. Therefore, the reduction in 1990 will be about 43 per cent from current levels.

In addition, the Regulation will require Hydro to install low NO_x burners at its larger coal-fired stations. This action should result in a maximum of roughly 60,000 metric tons of NO_x in 1985, and about 40,000 metric tons in 1990. This amount will decline further between 1985 and 1990 because less coal-fired generation will be occurring at the end of this decade.

Ontario Hydro has also been asked to investigate the implementation of a new operating philosophy, designed to minimize atmospheric emissions from Hydro's three biggest coal-fired stations--Nanticoke, Lambton and Lakeview. These three plants account for more than 90 percent of Hydro's SO₂ emissions.

The name of the operating philosophy is the Least Emissions Dispatching System (L.E.D.S.). This concept is being considered by the U.S. Government. If implemented, it would lead to significant reductions in emissions from

existing plants, without the use of any additional pollution control equipment or special fuels. Under the L.E.D.S. philosophy, a utility generates power from its "cleanest" plants first, and its "dirtiest" plants last. This ensures that plants already having pollution control measures are utilized fully, and not allowed to stand idle.

Ontario Hydro has complied with this request and will shortly be producing a report. At that time, a decision will be made as to whether L.E.D.S. should be implemented.

8.2 Negotiation of Agreement Leading to Abatement

On August 5, 1980 the Federal Governments of Canada and the United States signed the "Memorandum of Intent". Ontario is represented on all Work Groups which were formed as a consequence of this action, and is playing a significant role in the formulation of reports coming from these work groups.

All committees were charged with the responsibility of preparing and submitting interim reports by January 15, 1981 and first reports by May 1981. These reports are to form the basis for negotiations scheduled to start late in 1981. The committees are to produce final reports by January 1982.

As part of the technical input to these activities, Ontario is contributing the knowledge and expertise it has developed in its major environmental program, already underway, entitled the "Acidic Precipitation In Ontario Study" (A.P.I.O.S.) which has the following objectives:

- (1) To identify and quantify by means of field investigations Ontario's contribution to the atmospheric burden of SO_2 as well as the long range component of this burden;
- (2) To develop atmospheric transport models and use them to determine how sources of SO_2 are impacting on sensitive ecological areas;
- (3) To quantify the deposition of acidic substances in Ontario;
- (4) To assess the terrestrial and aquatic significance of the deposition of acidic substances in Ontario;
- (5) To assess socio-economic impacts and options to deal with the phenomenon from the perspective of costs and benefits.

The results of A.P.I.O.S. are also being used to formulate policies in Ontario and in Canada.

8.3 Interim Activities

Ontario has enforced in the past, is currently enforcing and will continue to enforce vigorously its existing regulations. Additionally, Ontario has proceeded with an aggressive program to identify major emission sources which contribute to acid deposition. This program is expanding, updating, and refining the scientific and engineering data base. As these results become available, Ontario is issuing and enforcing new regulations which will further reduce SO₂ emissions.

On the international front, Ontario is undertaking five actions.

First, the Ontario government is participating wholeheartedly in the Canada-United States Working Groups on acid deposition. These scientific groups are laying the foundation for the urgently needed air quality agreement with our American neighbours.

Second, Ontario is pressing the U.S. government to enforce vigorously its existing SO₂ emission standards, as set out in the various State Implementation Plans. This submission comprises one part of this activity.

Third, we are urging adequate evaluation of the cumulative effects of any proposed SIP revisions on Ontario and other provinces.

Fourth, the government of Ontario is opposing any actions by the U.S. and State governments which relax the existing SIP requirements.

Fifth, Ontario seeks to participate in any U.S. proceedings which could effect, as a result of long range transport, our environmental quality.

Ontario is undertaking these five actions because its leadership in reducing acid deposition within its jurisdiction will be of little consequence unless other jurisdictions follow this lead, due to the nature of the problem, that is, the transboundary exchange of pollutants between Canada and the United States. Canada receives two to four times the amount of SO_x from the U.S. than it sends to the U.S., and the NO_x exchange is 11 times greater from the United States to Canada.²

A review of emission trends from U.S. sources over the past forty years clarifies and substantiates this statement. First and foremost, SO_2 emissions have increased by about forty percent. Although SO_2 emissions have decreased

from most economic sectors during this period, the electric utility sector's emissions increased by more than a factor of six during this same period.³ Second, the increase in SO₂ emissions from this one sector occurred concurrently with a substantial increase (by approximately a factor of five) in the stack height for utility sources.⁴ Third, SO₂ emissions from coal burning changed from a wintertime peak to a more level rate throughout the year, with a small peak in the summer emission rate.⁵ Fourth, the precursor emissions for photochemical oxidants increased markedly during this time.³ In the earlier parts of this century, photochemical smog was hardly recognizable as a problem. Now, however, photochemically-produced oxidants frequently blanket the continental Northeast during the summer months.⁶ Fifth, total NO_x emissions approximately quadrupled during this period.³

These trends suggest a situation in which the atmosphere has become chemically more reactive. Simultaneously, greater quantities of acid-forming precursors are being added to the atmosphere. Further, a substantially greater quantity of these emissions is now injected high into the mixed layer where the emissions and their reaction products have much longer residence times as they travel to areas remote from their points of origin.

In Ontario, there is firm scientific evidence that if these emissions of sulphur dioxide continue, or

increase, the resultant acidic pollutants are threatening to kill aquatic life in thousands of Ontario lakes and waterways within the brief span of another 10 to 20 years. Serious concern also exists that damage to terrestrial life forms may also occur, and that man-made structures will be impacted.

With the substantial increase in the use of coal as a source of energy in the United States, and the projected increases in SO₂ and NO_x emissions in the U.S. between now and the year 2000, controls to reduce existing U.S. utility emissions are vital to the protection of Ontario's environment and that of Eastern Canada. The United States SO₂ emissions from power utilities are estimated at 18.6 million metric tons annually,² accounting for roughly two-thirds of total SO₂ emissions--compared with total SO₂ power utility emissions in Canada of 700,000⁷ metric tons annually.

In summary, because transboundary pollution is of critical concern to Ontario and Canada's eastern provinces, there is an immediate need to reduce the emissions of these serious pollutants from existing U.S. power plants as well as the hundreds of new plants which are expected to be built in the United States during the next two decades.

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REMEDIES SOUGHT

ONTARIO, THEREFORE, URGES:

9.1. (a) That the Administrator disapprove any SIP revisions in those proceedings which would result in any increase of permissible emissions of SO_2 .

(b) That the Administrator reconsider any SIP revisions already approved in these proceedings which result in any increase of permissible emissions of SO_2 and disapprove such revisions.

(c) That, the Administrator disapprove any future SIP revisions allowing increased SO_2 emissions which he may be called upon to consider.

9.2 That, in the event that the Administrator does not disapprove such revisions, he should, prior to making a decision, reopen and consolidate these proceedings and evaluate the cumulative effect of such revisions on Ontario and other Provinces and he should permit Ontario to participate in such reopened proceedings. Included in any such evaluation and consolidation should be any other SIP revisions which involve relaxations of SO_2 emissions that the Administrator may be called

upon to consider.

- 9.3 That, in any event, the Administrator take all steps necessary to assure effective enforcement of existing SO₂ emission standards.

THE PROVINCE OF ONTARIO

A Submission to the United States Environmental Protection Agency Hearings on Interstate Pollution Abatement

Washington, D.C.
June 19, 1981



Ministry
of the
Environment

Hon. Keith C. Norton, Q.C.,
Minister

Graham W. S. Scott, Q.C.,
Deputy Minister

INTRODUCTION

REPRESENTATIVES OF THE ONTARIO MINISTRY OF THE ENVIRONMENT PRESENTED TECHNICAL EVIDENCE ON TRANSBOUNDARY AIR POLLUTION TO A HEARING PANEL OF THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY IN WASHINGTON, D.C., ON JUNE 19, 1981.

THE ONTARIO PRESENTATION HAD TWO MAIN THRUSTS:

1. TO ILLUSTRATE THE EFFECTS OF TRANSBOUNDARY POLLUTION ON THE NEW YORK, PENNSYLVANIA AND ONTARIO REGIONS.
2. TO DISCUSS ONTARIO'S EXPERIENCES IN CONSIDERING AND CONTROLLING AGGREGATED SO_2 SOURCES IN RELATION TO TRANSBOUNDARY POLLUTION, AND TO SHOW HOW ONTARIO HAS USED LONG-RANGE TRANSPORT MODELLING IN THE CONSIDERATION AND CONTROL PROCESS.

DETAILED, WRITTEN EVIDENCE WAS TO BE PROVIDED TO THE EPA BY AUGUST, 1981.

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AND A FILM BY DR. WALTER LYONS, CONSULTANT TO THE
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METEOROLOGICAL PATTERNS AND POLLUTION EPISODES
AFFECTING ONTARIO, PENNSYLVANIA, AND NEW YORK: THE
DEVELOPMENT OF EVIDENCE")

GRAHAM W.S. SCOTT, Q.C.

DEPUTY MINISTER

THE ONTARIO MINISTRY OF THE ENVIRONMENT

NOTES ON

TRANSBOUNDARY AIR POLLUTION

HEARINGS ON INTERSTATE POLLUTION ABATEMENT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C.

JUNE 19TH, 1981

FOR RELEASE AT 6:00 P.M.

MR. CHAIRMAN, MEMBERS OF THE PANEL:

AS A FRIEND AND CLOSE NEIGHBOUR OF THE AMERICAN PEOPLE, ONTARIO WELCOMES THIS OPPORTUNITY TO PARTICIPATE IN THESE PROCEEDINGS.

OUR APPEARANCE HERE TODAY IS SOMETHING OF A PRECEDENT. IT IS NOT COMMON FOR A DELEGATION FROM A PROVINCIAL GOVERNMENT TO APPEAR BEFORE ADMINISTRATIVE PROCEEDINGS IN ANOTHER COUNTRY. BUT THE MUTUAL PROBLEMS WHICH FACE US BOTH CALL FOR NEW APPROACHES AND BRING INTO QUESTION TRADITIONAL WAYS OF THINKING. ONTARIO IS AWARE, TOO, THAT THIS HEARING REPRESENTS A NEW DEPARTURE FOR THE ENVIRONMENTAL PROTECTION AGENCY IN THAT FOR THE FIRST TIME IT ADDRESSES THE QUESTION OF AGGREGATE IMPACT FROM A NUMBER OF POLLUTION SOURCES. WE FEEL THIS NEW INITIATIVE BY EPA IS ESSENTIAL IF THEY ARE TO MOVE TOWARDS A SUBSTANTIAL PROGRAM TO REDUCE EMISSIONS IN SEVERAL STATES.

THE U.S. LEGISLATORS WHO ENACTED SECTION 115 OF THE CLEAN AIR ACT IN ITS ORIGINAL FORM IN 1970 SHOWED GREAT FORESIGHT IN ADDRESSING TRANSBOUNDARY AIR POLLUTION. CONGRESS RECOGNIZED THE INCREASING SEVERITY OF THE PROBLEM IN 1977 BY AMENDING THE PROVISION TO MAKE IT MORE EFFECTIVELY ENFORCEABLE.

OUR PRESENTATION THIS EVENING OFFERS EVIDENCE RELEVANT TO PETITIONS BY NEW YORK AND PENNSYLVANIA AND HAS SEVERAL OBJECTIVES:

1. TO DEMONSTRATE THAT U.S. INDUSTRIAL EMISSIONS INCLUDING SO_2 AND PARTICULATES ARE BEING TRANSPORTED THROUGH A LARGE AIRSHED WHICH INCLUDE AREAS OF NEW YORK AND PENNSYLVANIA AND ONTARIO;
2. TO SHOW THE EFFECT OF THE TRANSPORTED MATERIAL ON THE ENVIRONMENT;
3. TO INDICATE HOW ONTARIO IS DEALING WITH THE PROBLEM WITHIN ITS JURISDICTION;
4. TO CONVEY TO YOU OUR VIEW THAT THERE IS NEED TO RETHINK THE CURRENT REGULATORY MECHANISMS DEALING WITH INDUSTRIAL POLLUTANTS AND TO CONSIDER THE FOLLOWING ISSUES:
 - (A) MULTIPLE VS. SINGLE POINT SOURCES;
 - (B) LONGER-RANGE AS WELL AS SHORT-RANGE TRANSPORT;
 - (C) THE CONNECTION BETWEEN PRIMARY AND SECONDARY POLLUTANTS;
 - (D) TRANSBOUNDARY POLLUTION.

5. TO PROPOSE A LEGAL FRAMEWORK FOR THE RESOLUTION OF PROBLEMS COVERED BY THIS HEARING AND OTHER ASSOCIATED TRANSBOUNDARY PROBLEMS;

6. TO PERSUADE YOU TO IMPLEMENT A POLICY WHICH:

- (A) ENCOURAGES VIGOROUS ENFORCEMENT OF CURRENT REGULATIONS;
- (B) DISCOURAGES ANY RELAXATION IN THESE REGULATIONS;
- (C) ACHIEVES REDUCTION IN EMISSIONS WHICH WE BELIEVE TO BE NECESSARY.

CANADIAN PROVINCES ARE RESPONSIBLE FOR MANAGING THEIR OWN AIR QUALITY AND ONTARIO HAS DEVELOPED ITS OWN AMBIENT AIR QUALITY CRITERIA AND REGULATORY FRAMEWORK.

A LOOK AT THE MAP SHOWS THAT ONTARIO IS WEDGED BETWEEN A GROUP OF STATES WHICH ARE HIGHLY INDUSTRIALIZED. WIND DIRECTIONS INTO AND ACROSS ONTARIO HAVE A WESTERLY PREVALENCE. AIR MASSES HEAVILY LADENED WITH INDUSTRIAL EMISSIONS AND OFTEN RESULTING IN PRECIPITATION IN ONTARIO FREQUENTLY ORIGINATE FROM THE SOUTH AND SOUTHWEST.

OUR PRESENCE HERE UNDERLINES OUR VIEW THAT ATMOSPHERICALLY BORNE POLLUTANTS LIKE SO_2 ARE A PROBLEM WHICH INVOLVES US ALL.

AIRSHEDS CAN NO LONGER BE CONSIDERED AS AN ENTITY WITH LOCALIZED BOUNDARIES AND SUBJECT TO MANAGEMENT BASED ON A LOCAL RATIONALE. IN THE CASE OF ATMOSPHERICALLY CONVEYED POLLUTANTS WE SHARE A COMMON AIRSHED. THUS, POLLUTION CONTROL TO PROTECT THE NORTH AMERICAN ENVIRONMENT MUST BE A SHARED RESPONSIBILITY AND COMMITMENT.

CLEARLY ONTARIO HAS A REAL INTEREST IN THESE PROCEEDINGS. ONE NEEDS ONLY TO CONSIDER THE DAMAGE ALREADY DONE TO OUR RECREATIONAL AREAS AND AGRICULTURAL ZONES WHICH ARE SENSITIVE TO ATMOSPHERIC POLLUTANTS. IF FUTURE DAMAGE IS TO BE PREVENTED THEN A REDUCTION OF EMISSIONS IS NEEDED ON AN EASTERN NORTH AMERICAN BASIS.

WE UNDERSTAND THAT THE HEARINGS ARE BEING CONDUCTED UNDER THE AUTHORITY OF SECTION 136 OF THE CLEAN AIR ACT. THIS PROVIDES A MECHANISM FOR ANY STATE, IN THIS CASE NEW YORK AND PENNSYLVANIA, TO PETITION THE EPA TO DETERMINE WHETHER A MAJOR POLLUTION SOURCE IN ANOTHER STATE IS CAUSING AN INTERSTATE POLLUTION PROBLEM. THE HEARING NOTICE ALSO INDICATES THAT EPA UNDER SECTION 126 CAN ONLY REGULATE EMISSIONS SHOWN TO PREVENT ATTAINMENT OR MAINTENANCE OF A NATIONAL STANDARD OR INTERFERE WITH MEASURES TO PREVENT SIGNIFICANT DETERIORATION OR PROTECT VISIBILITY.

THE SCOPE OF THE HEARING AS DEFINED BY THESE TERMS OF REFERENCE IS THEREFORE LIMITED TO SO_2 , TOTAL SUSPENDED PARTICULATES AND VISIBILITY WITH REFERENCE TO THE PETITIONING STATES, NEW YORK AND PENNSYLVANIA. THESE TERMS OF REFERENCE DO NOT PROVIDE AN OPPORTUNITY FOR US TO MAKE OUR FULL CASE WITH RESPECT TO TRANSBOUNDARY POLLUTION AND IN PARTICULAR ACID PRECIPITATION AND ITS EFFECTS ON ONTARIO. WE ALSO UNDERSTAND THAT THE EPA REGARDS THESE PROCEEDINGS UNDER SECTION 126 AS BEING ENTIRELY SEPARATE FROM SEVERAL PROPOSED STATE IMPLEMENTATION PLANS AMENDMENTS NOW UNDER CONSIDERATION BY EPA AND IN RESPECT OF WHICH ONTARIO HAS FILED SUBMISSIONS. WE DO NOT SEE HOW THESE MATTERS CAN, IN PRACTICE, BE TREATED IN ISOLATION FROM EACH OTHER SINCE THE SO_2 EMISSIONS FROM THE SAME SOURCES ARE AN ISSUE IN EACH CASE.

BASED ON OUR SCIENTIFIC EXPERIENCE WE FEEL THAT THERE IS A CLEAR NEED TO TAKE AN INTEGRATED AND BROAD VIEW OF THE MANY ASPECTS OF THE PROBLEM OF LONG-RANGE TRANSPORT OF ATMOSPHERIC POLLUTANTS. FOR THIS REASON WE FILED WITH EPA ON MAY 28, 1981, A REQUEST "THAT EPA EXPAND THE SCOPE OF THE HEARINGS IT HAS ANNOUNCED UNDER SECTION 126 OF THE CLEAN AIR ACT TO INCLUDE CLOSELY RELATED INFORMATION THAT IS RELEVANT TO THE AGENCY'S OBLIGATIONS UNDER SECTION 115 OF THE CLEAN AIR ACT".

WE LEARNED AT THE OUTSET OF THESE HEARINGS THAT THIS REQUEST HAS BEEN REJECTED.

EVEN GIVEN OUR PROBLEM WITH THE TERMS OF REFERENCE OUR EVIDENCE IS RELEVANT TO THE IMPACT ON NEW YORK AND PENNSYLVANIA. WE HAVE DIRECTED OUR TESTIMONY TOWARDS THE ISSUES ON WHICH COMMENT IS INVITED IN THE FEDERAL REGISTER NOTICE. THIS INCLUDES QUESTIONS OF WHETHER THE SOURCES IDENTIFIED RESULT IN UNACCEPTABLE INTERSTATE IMPACT, WHETHER THE EFFECTS OF THESE SOURCES SHOULD BE CONSIDERED IN THE AGGREGATE, WHETHER LONG-RANGE MODELS ARE AVAILABLE AND HOW THE MODELS CAN BE USED. AS MUCH AS POSSIBLE OUR EVIDENCE DEALS WITH THE IMPACT OF SULFUR DIOXIDE, PARTICULATE AND VISIBILITY ON THE STATES OF NEW YORK AND PENNSYLVANIA.

FOR SEVERAL DECADES, ONTARIO HAS BEEN WELL AWARE OF DAMAGE TO VEGETATION AND SURFACE WATERS CAUSED BY SO_2 IN THE AREA AROUND SUDBURY. HIGH AMBIENT SO_2 CONCENTRATIONS CAUSED BY NON-FERROUS SMELTERS HAVE DESTROYED FORESTS. THE ACIDIFYING EFFECT OF SO_2 AS IT REACTS DIRECTLY WITH SURFACE WATERS OR INDIRECTLY WITH MOISTURE IN THE AIR AND IS THEN DEPOSITED, HAS ALTERED SURFACE WATER CHEMISTRY AND LED TO THE DESTRUCTION OF FISH POPULATIONS IN NUMEROUS LAKES IN THE AREA. THE ENVIRONMENTAL DAMAGE HAS BEEN WELL STUDIED AND THE CASE IS WELL-KNOWN AS AN EXAMPLE OF SO_2 DAMAGE.

NON-FERROUS SMELTERS HAVE OPERATED IN SUDBURY SINCE THE LATE 1880'S. ONE COMPANY IN THE AREA, INCO LIMITED, IS THE LARGEST POINT SOURCE OF SO_2 IN THE WORLD.

IN THE 1960'S, ONTARIO GOVERNMENT CONTROL ORDERS REQUIRED THE REDUCTION OF SO_2 EMISSIONS AND THE CONSTRUCTION OF THE WORLD'S HIGHEST STACK TO DISPERSE THE REMAINING SO_2 . TODAY SO_2 EMISSIONS HAVE BEEN REDUCED BY SOME 60% AND PLANT EMISSIONS ARE FURTHER CONTROLLED AS A FUNCTION OF WEATHER CONDITIONS.

IN SUDBURY, AS IN OTHER PARTS OF NORTH AMERICA, HIGH STACKS FOR DISPERSION PURPOSES WERE AN ACCEPTABLE APPROACH TO ADDRESS LOCAL AMBIENT AIR NEEDS.

IN THE U.S., MORE THAN 175 SMOKE STACKS EXCEEDING 500 FEET HAVE BEEN CONSTRUCTED SINCE 1970. ALL BUT 8 ARE AT POWER PLANTS WITH EMISSIONS WHICH CAN CONTRIBUTE TO VISIBILITY DETERIORATION AND ACID DEPOSITION IN DISTANT AREAS (EPA, 1979).

IN 1975, ONTARIO BEGAN A DETAILED STUDY OF LAKES IN THE DORSET AREA WITH THE OBJECTIVE OF DETERMINING THE EFFECTS OF COTTAGE DEVELOPMENT ON WATER QUALITY. WITHIN THE FIRST YEAR OF THE STUDY IT WAS LEARNED THAT ATMOSPHERIC ACID LOADINGS TO THE LAKES WERE ELEVATED AND THAT SURFACE WATER QUALITY WAS BEING AFFECTED.

THE AREA IS REMOTE FROM SOURCES OF SO_2 AND LIES IN PRECAMBRIAN SHIELD BEDROCK. THE BEDROCK AND THIN SOILS AND SURFACE WATERS HAVE MUCH LESS CAPACITY TO NEUTRALIZE ACIDS THAN THE ALKALINE SOILS OF SOUTHERN ONTARIO. THE GEOLOGY OF THE AREA IS SIMILAR TO THE ADIRONDACK MOUNTAINS IN NEW YORK WHERE LAKES HAVE BEEN ACIDIFIED AND FISH POPULATIONS LOST IN THE PAST FEW DECADES.

THE POSSIBILITY IMMEDIATELY AROSE THAT THE SUDBURY EMISSIONS OF SO_2 WERE SIMPLY BEING DEPOSITED FURTHER AFIELD. DATA WHICH WILL BE DISCUSSED IN DETAIL LATER RESOLVED THAT PARTICULAR ISSUE.

PRECIPITATION DATA HAS INDICATED THAT 70-85% OF THE SULFUR BEING DEPOSITED IN THE DORSET AREA ORIGINATED IN THE SOUTH AND SOUTHWEST.

IT WAS THEREFORE FULLY ESTABLISHED THAT THE LONG-RANGE TRANSPORT AND DEPOSITION OF POLLUTANTS AND RESULTING SURFACE WATER QUALITY EFFECTS ARE WELL-DOCUMENTED IN EUROPE AND ARE A REALITY IN ONTARIO.

IN LIGHT OF THESE REALIZATIONS WE BECAME AWARE OF THE NEED TO LOOK BEYOND OUR OWN BOUNDARY TO DEVELOP THE NECESSARY COMPREHENSIVE APPROACH TO THIS PROBLEM. IN CO-OPERATION WITH THE FEDERAL GOVERNMENT WE DIRECTED CONSIDERABLE RESOURCES INTO WORKING ON AN INTERNATIONAL SOLUTION.

THE FIRST CONSTRUCTIVE STEP WAS THE MEMORANDUM OF INTENT ON TRANSBOUNDARY AIR POLLUTION SIGNED ON AUGUST 5, 1980, WHICH COMMITTED BOTH NATIONS TO RESIST EMISSION INCREASES AND TO BRING ABOUT REDUCTIONS WHERE POSSIBLE, PENDING CONCLUSION OF A COMPREHENSIVE INTERNATIONAL AGREEMENT.

UNDER THIS DOCUMENT, BOTH THE U.S. AND CANADA UNDERTOOK TO TAKE CERTAIN INTERIM ACTIONS. THESE INCLUDED THE DEVELOPMENT OF AIR POLLUTION CONTROL STRATEGIES AND THE VIGOROUS ENFORCEMENT OF EXISTING LAWS AND REGULATIONS "IN A WAY WHICH IS RESPONSIVE TO THE PROBLEMS OF TRANSBOUNDARY AIR POLLUTION".

INTERIM REPORTS HAVE BEEN PUBLISHED AND THE IMPACT DOCUMENTS SHOW THERE IS NO LONGER A QUESTION OF "JUST HOLDING THE LINE". CLEARLY, SULFUR DEPOSITION MUST BE REDUCED IF ECOSYSTEMS ARE TO BE PROTECTED IN THE FUTURE.

THERE ARE MANY UNRESOLVED PROBLEMS WITH RESPECT TO THE PHENOMENON OF LONG-RANGE TRANSPORT OF ATMOSPHERIC POLLUTANTS AND ONTARIO IS CONTRIBUTING HEAVILY TO INTERNATIONAL RESEARCH EFFORTS TO RESOLVE THESE PROBLEMS.

I CANNOT ACCEPT, HOWEVER, ANY ASSERTION THAT WE DO NOT HAVE ENOUGH EVIDENCE TODAY FOR GOVERNMENT TO TAKE FURTHER STEPS TO ABATE SULFUR DIOXIDE EMISSIONS.

THE FACT IS, THAT WE ALREADY HAVE SUFFICIENT SCIENTIFIC EVIDENCE OF THE DANGER OF LONG-RANGE TRANSPORT AND ITS ENVIRONMENTAL CONSEQUENCES AND WE ARE PAINFULLY AWARE OF THE LIMITED TIME-FRAME IN WHICH ACTION MUST BE TAKEN.

I AM REFERRING PARTICULARLY HERE TO THE LAKES AND AQUATIC LIFE IN THOSE AREAS OF CANADA AND THE U.S. WHICH ARE PARTICULARLY SENSITIVE TO THE DEPOSITION OR FALLOUT OF THESE POLLUTANTS.

AT SOME POINT IT BECOMES NECESSARY FOR GOVERNMENTS TO TAKE ACTION ON THE BEST EVIDENCE AVAILABLE WITHOUT WAITING UNTIL ALL OF THESE SCIENTIFIC QUESTIONS HAVE BEEN ANSWERED TO THE SATISFACTION OF EVERYONE. LET ME TAKE AN EXAMPLE: MORE THAN A DECADE AGO IT BECAME WIDELY RECOGNIZED THAT PHOSPHORUS LOADINGS WERE CAUSING SEVERE STRESSES IN THE GREAT LAKES. HAD A DECISION BEEN TAKEN TO POSTPONE CORRECTIVE ACTION UNTIL ALL OF THE SCIENTIFIC QUESTIONS HAD BEEN ANSWERED, WE WOULD STILL BE WAITING TODAY.

IF, FOR EXAMPLE, REGULATORY AGENCIES HAD INSISTED ON ESTABLISHING WITH CERTAINTY THE RELATIONSHIP BETWEEN THE OBSERVED EFFECTS AND EACH POTENTIAL SOURCE, THOSE LAKES WOULD BE SLOWLY STRANGLING.

INSTEAD WE HAVE SEEN A STEADY IMPROVEMENT AND RECOVERY IN THOSE LAKES, DIRECTLY ATTRIBUTABLE TO THE CONTROL MEASURES THAT WERE IMPLEMENTED.

MY VIEW IS SHARED BY THE JOINT CHAIRMEN OF THE CANADA/ U.S. CO-ORDINATING COMMITTEE AND I QUOTE FROM THEIR LETTER OF TRANSMITTAL FOR THE FEBRUARY, 1981 INTERIM REPORT, "FURTHER RESEARCH MUST OBVIOUSLY CONTINUE BUT SOLUTIONS SHOULD BE SOUGHT IN THE NEAR TERM".

THE SIGNIFICANCE OF ENFORCEMENT IS UNDERLINED BY EPA'S OHIO RIVER BASIN ENVIRONMENT STUDY (ORBES) IN WHICH IT IS STATED ON PAGE 13 THAT TOTAL SULFUR DIOXIDE EMISSIONS FROM THE STATES STUDIED COULD BE REDUCED BY 1/3 BY 1985 BY REQUIRING COMPLIANCE WITH CURRENT SIP SO_2 EMISSION LIMITS.

THE REPORT ALSO SHOWS (FIGURE ES-4, PG. 11) THAT IF THE SIP STANDARDS ARE NOT COMPLIED WITH AND NO COMPLIANCE SCHEDULE IS ENFORCED, EMISSIONS WILL CONTINUE TO RISE UNTIL 1987. BY THE END OF THE CENTURY THEY WOULD ONLY BE SLIGHTLY BELOW CURRENT LEVELS. EVEN THIS ASSUMES THAT THE PLANTS WILL BE RETIRED AFTER 35 YEARS OF USE. IF THIS DOES NOT OCCUR, THE EMISSION LINE WOULD CONTINUE TO MOVE STEADILY UPWARD.

I WANT TO DEAL NEXT WITH THE MEASURES WE ARE TAKING IN ONTARIO WHICH ARE IN THE SPIRIT OF INTERIM COMMITMENTS UNDER THE MEMORANDUM AND IN LINE WITH THE NEED TO TAKE STEPS NOW.

I AM GOING TO RETURN TO THE CASE OF INCO AT SUDBURY. ON SEPTEMBER 2, 1980, A NEW SET OF CONTROLS WAS ENACTED UNDER A STATUTORY POWER ENABLING THE LIEUTENANT GOVERNOR IN COUNCIL TO MAKE REGULATIONS REGULATING THE EMISSION OF CONTAMINANTS "INTO THE NATURAL ENVIRONMENT FROM ANY SOURCE OF CONTAMINANTS OR ANY CLASS THEREOF".

A REGULATION IN OUR JURISDICTION IS SUBORDINATE LEGISLATION HAVING THE SAME EFFECT AS A STATUTE. IT IS NOT SUBJECT TO ANY STATUTORY APPEAL. IF IT IS WITHIN THE STATUTORY POWER AND MADE IN GOOD FAITH, IT IS ALMOST UNASSAILABLE IN THE COURTS.

I OUTLINE THE NATURE OF THIS ACTION, NOT IN AN ATTEMPT TO PERSUADE YOU TO FOLLOW OUR LAWS AND PROCEDURES, BUT RATHER TO UNDERLINE THE EXTREME SERIOUSNESS WITH WHICH THIS ISSUE IS REGARDED BY THE ONTARIO PUBLIC.

UNDER THE REGULATIONS, INCO IS REQUIRED TO REDUCE ITS EMISSIONS BY JANUARY 1, 1983, TO A LEVEL WHICH REPRESENTS A 70% REDUCTION FROM THE LATE 1960's. THE EMISSIONS ARE TO BE KEPT AT THAT LEVEL REGARDLESS OF PRODUCTION. THIS CAN ONLY BE ACCOMPLISHED BY INNOVATIVE CHANGES IN THE METALLURGICAL PROCESS AND PRELIMINARY WORK IS ALREADY UNDERWAY TO ACCOMPLISH THESE CHANGES.

THE INCO REGULATION IS AN INTERIM MEASURE. A CANADA/ONTARIO TASK FORCE WILL REPORT THIS AUTUMN ON OPTIONS TO REDUCE INCO'S EMISSIONS TO THE LOWEST POSSIBLE LEVEL.

THE SECOND LARGEST SOURCE OF ACID CAUSING POLLUTANTS IN ONTARIO IS ONTARIO HYDRO'S THERMAL PLANTS. ON FEBRUARY 17, 1981, A REGULATION WAS FILED WHICH PLACES A CEILING ON FUTURE EMISSIONS FROM THE COAL-FIRED STATIONS OPERATED BY ONTARIO HYDRO. IT WILL REQUIRE A 43% REDUCTION FROM CURRENT LEVELS BY THE YEAR 1990. FROM THAT DATE SO₂ EMISSIONS CANNOT EXCEED A CEILING OF 260,000 METRIC TONS NOTWITHSTANDING INCREASES IN ELECTRICAL OUTPUT FROM THE SYSTEM.

HYDRO WAS ALSO ADVISED THAT FURTHER RESTRICTIONS MAY BE FORTHCOMING AS A RESULT OF THE FUTURE OF A CANADA/U.S. AGREEMENT ON TRANSBOUNDARY POLLUTION.

FURTHER, AT THE REQUEST OF THE GOVERNMENT, ONTARIO HYDRO IS INVESTIGATING THE IMPLEMENTATION OF THE LEAST EMISSION DISPATCH SYSTEM (L.E.D.S.) WHICH WOULD LEAD TO FURTHER SIGNIFICANT REDUCTIONS FROM EXISTING PLANTS. UNDER THIS SYSTEM THE UTILITY GENERATES POWER FROM ITS "CLEANEST" PLANT FIRST AND ITS "DIRTIEST" PLANT LAST.

IT IS IMPORTANT TO NOTE THAT THESE CONTROL MEASURES ON INCO AND ONTARIO HYDRO TAKEN IN ADVANCE OF AN INTERNATIONAL AGREEMENT AND TAKEN TO DEAL WITH LONG-RANGE TRANSPORT AND ACID RAIN, ARE ADDRESSED TO LIMITING LOADINGS OF SO_2 . THIS QUESTION OF LOADINGS WAS ADDRESSED IN THE REPORT OF THE NATIONAL COMMISSION ON AIR QUALITY "TO BREATHE CLEAN AIR" ISSUED MARCH, 1981. THE REPORT STATES:

I QUOTE:

"THE NATIONAL AMBIENT AIR QUALITY STANDARDS ARE THE CORNERSTONE OF THE CLEAN AIR ACT PROGRAM FOR THE CONTROL OF POLLUTION FROM EXISTING STATIONARY SOURCES. HOWEVER, THE KEY FACTOR ASSOCIATED WITH THE MOST SERIOUS ENVIRONMENTAL EFFECTS OF A PROBLEM SUCH AS ACID DEPOSITION IS NOT AMBIENT POLLUTANT CONCENTRATION BUT RATHER TOTAL POLLUTANT LOADING, WHICH IS ONLY INDIRECTLY LINKED TO AMBIENT CONCENTRATIONS (ELI, 1981). LARGE QUANTITIES OF POLLUTION CAN BE RELEASED WITHOUT VIOLATING AMBIENT STANDARDS IN AN AREA IF THE EMISSIONS ARE SUFFICIENTLY DISPERSED. THEREFORE, IT IS POSSIBLE FOR A STATE TO INSTITUTE A CONTROL PROGRAM SUFFICIENTLY STRINGENT TO PROTECT LOCAL HEALTH, AS DEFINED BY PRIMARY NATIONAL AMBIENT AIR QUALITY STANDARDS, BUT THAT STILL PERMITS POLLUTANT EMISSIONS THAT CAN CAUSE SERIOUS ACID DEPOSITION PROBLEMS IN DISTANT DOWNWIND REGIONS." (P.3.9-2).

IN LIGHT OF THIS, WE WOULD URGE THAT YOU PURSUE POLICIES CONSISTENT WITH THE DECLARED INTENTIONS OF OUR TWO COUNTRIES IN THE MEMORANDUM OF INTENT, TO VIGOROUSLY ENFORCE CURRENT REGULATIONS, DISCOURAGE RELAXATION OF THESE REGULATIONS AND TO ACHIEVE ADDITIONAL REDUCTIONS WHEREVER POSSIBLE.

LET ME NOW ADDRESS THE SPIRIT IN WHICH THE EVIDENCE SHOULD BE APPROACHED. IT IS IMPORTANT TO TAKE INTO ACCOUNT ALL THE EVIDENCE AVAILABLE TO YOU, GIVING EACH PIECE ITS APPROPRIATE WEIGHT.

YOU SHOULD NOT LOOK AT ANY PIECE OF EVIDENCE IN ISOLATION, BUT IN THE CONTEXT OF WHAT ALL THE EVIDENCE IS TELLING YOU. THE MAGNITUDE AND DISTRIBUTION OF SOURCES, METEOROLOGY, BACK TRAJECTORY ANALYSES, SATELLITE OBSERVATIONS, SPECIFIC LONG-RANGE TRANSPORT OF POLLUTION EPISODES, AND MODELLING ACTIVITIES WHICH PULL ALL THIS DIVERSE EVIDENCE TOGETHER.

ALL OF THIS IS REQUIRED TO UNDERSTAND AND COMBAT THE PHENOMENA OF ACID RAIN. WITHOUT THIS TOTAL APPROACH WE SEVERELY CRIPPLE OUR COLLECTIVE ABILITY TO PROTECT OUR SENSITIVE ENVIRONMENTS.

TESTIMONY OF BRUCE J. TERRIS
ON BEHALF OF THE PROVINCE OF
ONTARIO, CANADA AT THE EPA
SECTION 126 HEARING, JUNE 19, 1981

Good afternoon. My name is Bruce J. Terris. I am an attorney with the law firm of Terris & Sunderland in Washington, D.C. I am here this afternoon representing the Province of Ontario, Canada.

Mr. Scott, Ontario's Deputy Minister of the Environment, has already spoken of Ontario's interest in these proceedings. The emissions sources which are the subject of these hearings not only threaten New York's and Pennsylvania's efforts to comply with the Clean Air Act. These sources also contribute significantly to the formation of acid deposition that is already severely harming the environment of Ontario. Any emissions reductions that result from these proceedings will benefit the Province of Ontario. Thus, the Province has an extremely important stake in the outcome of these proceedings. We therefore appreciate the opportunity to appear before you this afternoon to discuss with you the proper approach to remedying the serious problems which Canada and the United States face relating to the long-range transport of pollutants.

My first point concerns the status of these hearings under Section 126. Two sections of the Clean Air Act are relevant in ascertaining the procedures which the agency should follow when addressing interstate pollution.

Section 126(b) provides that "within 60 days after receipt of any petition under this subsection and after public hearing, the Administrator shall make such a finding [of interstate air pollution] or deny the petition."

Section 307(d) (1) (M) provides that Section 307 rulemaking procedures apply to "action of the Administrator under section 7426 of this title (relating to interstate pollution abatement) * * *." Under Section 307(d) (3), a rulemaking begins with the publication in the Federal Register of a notice of proposed rulemaking which "shall be accompanied by a statement of its basis and purpose * * *." The contents of the statement of basis and purpose are specified by the statute as follows (ibid.):

The statement of basis and purpose shall include a summary of ---

- (A) the factual data on which the proposed rule is based;
- (B) the methodology used in obtaining the data and in analyzing the data; and
- (C) the major legal interpretations and policy considerations underlying the proposed rule.

* * *

All data, information and documents referred to in this paragraph on which the proposed rule relies shall be included in the docket on the date of publication of the proposed rule.

EPA's May 1, 1981, announcement of these hearings (46 Fed. Reg. 24602) clearly does not satisfy the requirements of a notice of proposed rulemaking under Section 307. The rulemaking will therefore not begin until after these hearings when EPA announces its proposed determination and satisfies the burden of production imposed by Section 307(d)(3) by placing relevant evidence, and EPA's analysis of that evidence, on the rulemaking record for scrutiny.

If EPA tentatively decides to grant New York's and Pennsylvania's petitions, then I think it is clear that the agency must publish a notice of proposed rulemaking complying with the requirements of Section 307(d)(3). After that notice is published, and after EPA has satisfied the requirement of producing information, then Section 307(d)(5) will require the agency to give interested persons another opportunity to submit comments, orally and in writing.

We note that this second set of comments is not a duplication of the comment period the agency is now conducting. The crucial difference is that the second stage of these proceedings centers on EPA's proposed determination and the evidence the agency has produced and placed on the rulemaking

record. At this earlier stage, we are addressing only the threshold question of whether EPA's proposed determination should be affirmative or negative, based on the evidence that has been submitted by the two petitioning states and any other persons who choose to present evidence.

If EPA decides to deny New York's and Pennsylvania's petitions, the agency still must comply with Section 307's procedural requirements before it can become final. Section 307 applies to "action of the Administrator" under Section 126 (Section 307(d)(1)(M)) (emphasis added). The use of the generic term "action" rather than the word "finding" -- the term used by Section 126 to describe an affirmative decision -- indicates that Section 307 procedures are intended to apply whether the agency's initial decision is affirmative or negative.

This reading of Sections 126 and 307 is consistent with the significance that the EPA should attach to the filing of a Section 126 petition. These are not ordinary rule-making petitions. Government agencies must be free to deny most rulemaking petitions without elaborate procedures in order to enable the agency to dispose of frivolous petitions. Such an escape hatch is unnecessary in the case of Section 126(b)

because that section already has the built-in safeguard that it must be invoked by a state or political subdivision.

Moreover, rulemaking petitions in other contexts often ask the agency to make a discretionary decision about where to employ its limited resources. An agency should not be required to expend significant resources building a record justifying denial of a rulemaking petition if the reason for the denial is that the agency believes that the issues raised are relatively unimportant. That rationale, however, does not apply to a Section 126 petition. By enacting Section 126, and the corresponding provision of Section 110(a)(2)(E), Congress has made clear that EPA has the duty to deal with the issue of interstate impacts. Indeed, one can hardly imagine a more appropriate issue for federal intervention than interstate and international transport of pollutants.

Based on this analysis of Section 126, several issues fall into place. The purpose of this week's hearings becomes more clear. These initial proceedings should be viewed as aiding the agency in focusing the issues, gathering information, and making a preliminary determination on the merits of the petitions. This limited role is consistent with the short time period, 60 days, provided by Section 126(b) for the agency to respond to a petition under that section. This

initial stage serves a function similar to comment on an advance notice of proposed rulemaking, frequently referred to as an ANPR. The goal is to help the agency shape its proposed determination in a manner that allows the subsequent rulemaking proceeding to be tightly focused on the central, relevant issues. By this method, a better record should be produced, leading to a more informed, and more expeditious, final determination.

Moreover, the sequence of proceedings I have set forth helps to resolve the issues raised by Roger Strelow, counsel for many of the utilities affected by these petitions, in his letters of April 14 and June 8, 1981, to EPA. Mr. Strelow is concerned that the record as it currently stands does not allow for full analysis of the issues raised by the petitions. We submit the solution lies in Section 307. Once the agency has complied with the notice of proposed rulemaking requirements of Section 307(d)(3), all interested persons, including affected utilities, will have a full opportunity to comment meaningfully.

Mr. Strelow suggests that these proceedings should be bifurcated into two stages: first, a proceeding devoted to determining whether unlawful interstate impacts are occurring; and second, a proceeding dealing with questions of

remedy, if that proves necessary. We do not think that EPA is legally required to conduct a two-step procedure. It could hold a unified Section 307 proceeding on both interstate impacts and remedies. We do believe, however, that EPA has the discretionary authority to hold separate hearings on remedies and that it may well be appropriate to do so in this case.

In any event, the issue of remedies is not central to the issues before you in the present hearing. The issue today is whether an interstate air pollution problem exists which is covered by Section 126. As I will discuss later, we believe that the evidence in this proceeding clearly demonstrates that such a problem under Section 126 does exist and therefore further proceedings under Section 307 are required.

Second, I would like to address EPA's basic responsibility in this proceeding. Congress has been attempting to get EPA to remedy the problem of interstate pollution since 1970. In 1977, Congress concluded that EPA had so construed the Act that there was no effective mechanism to prevent interstate pollution. It therefore adopted Section 126 and made clear its intent to ensure that EPA take effective action.

EPA therefore has been emphatically told by Congress to make Section 126 work. Some speakers have said that Section 126 is a bad mechanism for solving the interstate pollution problem. They say that Section 126 will not be easy to implement. That is undoubtedly true because transboundary pollution raises difficult problems. But the fact is that Congress has plainly told EPA in 1970 and, more emphatically, in 1977, that interstate pollution problems are to be resolved and that Section 126 is to be a mechanism to resolve them. Thus, EPA does not have the choice to allege lack of scientific certainty, to note the procedural or remedial difficulties, or to raise other problems as reasons to throw up its hands. Instead, Congress imposed on EPA the duty, we submit, the non-discretionary duty, to construe Section 126 so that it will work.

Third, we strongly quarrel with Mr. Strelow as to where he suggests placing the burden in this proceeding. The petitioning state agencies have the initial responsibility to trigger Section 126(b). The importance of EPA's proposed determination creates strong incentives for the petitioners to submit as much evidence as feasible to support their positions. Since if EPA is to rely on that information, it needs to know how the information was obtained, petitioners have a strong incentive to submit full documentation for their claims.

Nonetheless, EPA bears the responsibility to gather information relevant to these petitions, not to sit as a passive

judge deciding whether the petitioners have met their burden of proof. It is not an umpire calling balls and strikes. Thus, in Office of Communication of United Church of Christ v. Federal Communications Commission, 425 F.2d 543, 548 (D.C. Cir. 1969), then Judge Burger held that "[t]he Commission * * * ha[s] an affirmative duty to assist in the development of a meaningful record which can serve as the basis for the evaluation of the licensee's performance of his duty * * *."

EPA has been charged with the responsibility to ensure that the Clean Air Act is fully and effectively carried out. EPA, not Pennsylvania, not New York, not Ontario, has this overriding responsibility. And this responsibility to carry out the Act clearly includes the prevention of interstate pollution.

EPA has previously argued, both in Federal Register notices relating to SIP relaxation and a court brief, that a Section 126 proceeding, not review of a SIP revision under Section 110, is the proper forum for considering aggregate pollution emissions. See 46 Fed. Reg. 24560 (May 1, 1981) (SIP revision for Consumer Power's Cobb plant); 46 Fed. Reg. 24946 (May 4, 1981) (SIP revision for Toledo Edison's Bayshore plant); Brief for Respondents, Pennsylvania v. U.S. Environmental Protection Agency, No. 79-1026 (C.A. 3) pages 34-35. That argument is totally indefensible if the EPA uses its decision

to deal with these issues under Section 126 as a method to shift the ultimate burden of proof to the receptor states. Section 126 is merely an alternate means of placing the subject of interstate impact in issue. The criteria for review are set forth in Section 110(a)(2)(E). EPA retains the ultimate responsibility to ensure that the interstate impacts prohibited by that section are not occurring. This is true whether the interstate impacts are examined in the context of review of a SIP or of a SIP revision or in response to a petition under Section 126. This is particularly true where EPA has failed, as here, to examine long-range impacts in its initial review of the underlying SIPs.

Fourth, the opponents to these petitions argue that there is insufficient evidence concerning long-range transport to support Pennsylvania's and New York's position. We submit that the evidence presented in this proceeding by New York and Pennsylvania and the evidence which Ontario will present demonstrates conclusively the serious transboundary pollution problem affecting the northeastern United States, as well as Canada. Indeed, we submit that everyone, EPA, the midwestern states and even industry, know that there is a significant transboundary air pollution problem affecting the northeast and Canada. The dispute is about the details, yes, important details, but still details. All the fighting over models, over trajectory analysis, over the comparative contribution of local and

distant sources, and all the other disputes should not obscure the fact that a serious transboundary problem exists and must be faced.

Fifth, we strongly reject the notion that lack of sufficient information requires that no action be taken until elaborate research programs are completed. Congress surely knew that there could be no scientific certainty concerning interstate pollution problems when it passed Section 126. It still wanted EPA to act.

Scientific certainty is always the argument for those who want to maintain the status quo. It is always the argument when government agencies are reluctant to act. But there is no scientific certainty for almost any of the requirements of the Clean Air Act. Moreover, there is no greater scientific certainty for most of the other actions taken by federal or state or local governments in many fields. The Court of Appeals for the District of Columbia Circuit has said it far better than I could in upholding an EPA action under the Clean Air Act in Ethyl Corp. v. Environmental Protection Agency, 541 F.2d 1, 24-25, 28-29 (D.C. Cir. 1976), certiorari denied, 96 S. Ct. 2662 (1976):

Questions involving the environment are particularly prone to uncertainty. Technological man has altered his environment in ways never before experienced or anticipated. * * * [T]he statutes -- and common sense -- demand regulatory action to prevent

harm, even if the regulator
is less than certain that harm
is otherwise inevitable.

* * *

Where a statute is precautionary in nature, the evidence difficult to come by, uncertain, or conflicting because it is on the frontiers of scientific knowledge, the regulations designed to protect the public health, and the decision that of an expert administrator, we will not demand rigorous step-by-step proof of cause and effect. * * * The Administrator may apply his expertise to draw conclusions from suspected, but not completely substantiated, relationships between facts, from trends among facts, from theoretical projects from imperfect data, from probative preliminary data not yet certifiable as "fact," and the like.

In short, it is the duty of EPA to carry out the statute using the best information available.

Sixth, it has been suggested that Section 126 is violated only if the pollutants transported from out-of-state sources make it impossible for the receptor state to achieve attainment with the national air quality standards. However, if this were the test, Section 126 would have no meaning whatsoever. It is always possible for a state to achieve attainment by limiting its own sources except for the virtually impossible situation where out-of-state sources will alone cause NAAQS violations in another state. In other words, if the possibility of submitting an approvable plan were the test, Ohio could send into Pennsylvania enough pollution to consume

90% of allowable emissions. If Pennsylvania can reduce their emissions to 10% of the national standard -- which, of course, is possible by declaring the entire state a wilderness area -- then Section 126 has not been violated. I submit that reading of the statute is ridiculous.

Indeed, it is not only possible for a state to meet the national air quality standards by controlling its own emissions, it is required to do so. Thus, all states have either attained the standards already or must have a plan to do so. If any state which either has attained the standards or has a plan to do so cannot invoke Section 126, then the only states which could do so would be those in violation of federal law. It is incredible to believe that Congress could have intended any such result.

The absurdity of the argument is demonstrated by Mr. Strelow's testimony. He argues that New York cannot invoke Section 126 because he claims, albeit erroneously, that it has met the national standards. Yet, at the same time, he argues that it cannot invoke Section 126 because it has not done a good enough job itself in controlling its own pollution sources. It is obvious that Mr. Strelow's arguments would never allow anyone to invoke Section 126.

We submit that the language and legislative history of Section 126 make clear that Section 126 applies if the source state significantly interferes with the attainment or maintenance of the national standards. We submit that this test is plainly satisfied when significant amounts of pollution are transported into the recipient state and, as a result, the recipient state is forced to impose significantly more stringent requirement on its pollution sources than the source state. In these circumstances, we submit that Section 126 has been violated even if there is no current violation of a national standard.

Seventh, EPA has asked whether it should be considering the cumulative impacts of sources or each source alone. EPA has already answered its own question in its brief filed only three months ago in Pennsylvania v. EPA in the Third Circuit (Docket No. 79-1025, p. 35):

As required by Section 126, EPA intends to hold a hearing in the near future to consider the issues raised in Pennsylvania's petition. That section 126 proceeding will be the appropriate forum for evaluating Pennsylvania's claims regarding cumulative out-of-state source impacts. * * * (E)missions impacts due to any identified out-of-state sources can be considered in a Section 126 proceeding. (emphasis added)

EPA's position that Section 126 is an appropriate forum to consider cumulative out-of-state sources is clearly correct. Section 126 would be effectively destroyed if each source is to be considered alone. Rarely, if ever, will a single source seriously interfere with attainment of national standards in another state. As I have emphasized, EPA's duty is to make

Section 126 work, not to leave it an empty shell.

Finally, while you have determined not to broaden the present hearing to consider international pollution under Section 115, I wish to restate Ontario's position that, when the time comes for EPA to consider the remedies for transboundary pollution, it is essential that interstate pollution in the northeastern United States and international pollution in southeastern Canada be considered together. I will not spend time today arguing that EPA has a responsibility under Section 115 to go forward with proceedings to abate long-range transport of pollutants that are endangering Ontario and other parts of Canada. We have set forth our views of EPA's obligations under Section 115, particularly in light of its January 16, 1981, determination, in our written request of May 28, 1981, to expand the scope of these hearings. We intend to continue to urge EPA's obligation to proceed to carry out its clear responsibilities under Section 115 in every appropriate forum.

In any event, it is obvious that the problems of interstate and international air pollution in the northeastern United States and Southeastern Canada are interrelated. I would therefore like to take a look down the road at the process which EPA should follow to devise a remedy under Section 126, compare it to the process appropriate for Section 115, and tentatively suggest how the two should be coordinated.

Section 126(c) provides, in effect, for a federal SIP revision. If the Section 126(b) finding has been made, affected sources must cease operations in three months, unless the Administrator provides for no more than a three-year phase-in of the necessary emissions reductions. There is no provision requiring any action by the state in which the source is located.

Under Section 115, a finding of international air pollution "shall be deemed to be a finding under Section 7410 (a) (2) (H) (ii) * * * which requires a plan revision with respect to so much of the applicable implementation plan as is inadequate to prevent or eliminate the endangerment * * *." In other words, a Section 115 finding requires the affected states to develop SIP revisions.

To return again to Section 126, if a petition filed under that section affects one or a few sources, it may make sense to have EPA establish the compliance schedule.

But, in the case of petitions that affect numerous sources, I can understand reluctance on the part of EPA to take on the task of creating new emissions limitations for so many sources. Furthermore, to the extent possible, it would be most consistent with the spirit of the Clean Air Act and its division of responsibilities between the federal government and the states to allow the states a major role in allocating reductions to the sources affected within their states.

By now, it should be clear how readily this scheme for implementing Section 126 can be integrated with the process outlined for Section 115. The procedural difference is that emissions reductions under Section 115 are to be adopted by the states as state SIP revisions whereas Section 126 appears to contemplate adoption of a federal compliance schedule. We submit that this is a distinction without a difference. As a practical matter, the source-by-source emissions reductions should be proposed by the states in the first instance, and they are subject to federal review in either case. EPA could make the symmetry complete by giving the states the option under Section 126 of adopting the reductions themselves through the SIP process and then, if the reductions are acceptable, declaring those reductions to constitute the schedule required by Section 126(c).

We do note, however, that there is a significant difference between Sections 126 and 115 as to the criteria for measuring the impacts in the receptor states. Under

Section 126, the criteria are the national ambient air quality standards, PSD increments and visibility. Under Section 115, the criteria are expressed in the general phrase "air pollution which may reasonably be anticipated to endanger public health or welfare in a foreign country." Thus, Section 115 encompasses pollutants, such as sulfates, and effects, such as acid rain, even though they are not subject to national air quality standards.

The reductions necessary to satisfy Section 126 may be more or less than the reductions necessary under Section 115. Nonetheless, the emissions, sources and states identified by New York and Pennsylvania are the same emissions, sources and states that are contributing to acid deposition in Ontario. It seems foolish to go through the time-consuming and difficult process of establishing emissions schedules necessary to satisfy one of these sections of the Clean Air Act and then have to repeat the whole process again to satisfy the requirements of the other. That is the kind of unnecessary regulatory duplication that we can all condemn.

We therefore urge that EPA deal concurrently in the subsequent stages of this proceeding with international and interstate long-range air pollution. We urge that it do so by publishing a notice of proposed rulemaking that complies with Section 307(d)(3) and invokes the authority of both Sections 126 and 115. The rulemaking should encom-

pass all major sources of SO₂ that EPA tentatively determines are contributing to long-range international and interstate pollution, including the formation of acid deposition affecting Canada.

In conclusion, based on the record of these Section 126 hearings and on the information otherwise available, we submit that EPA will be compelled to propose a finding that interstate air pollution is occurring in violation of Section 110(a)(2)(E) of the Clean Air Act. We also submit that EPA has already determined that Section 115 has been violated and that the agency has a mandatory duty to continue the efforts initiated on January 16, 1981, to implement that section. We therefore urge that you initiate pursuant to Section 307(d) a joint proceeding to consider in detail the international and interstate pollution involved and appropriate remedies for it.

A Brief Description Of How Ontario Dynamically Integrates
Policy and Rule Making with Information Gathering in Regard
To Transboundary Air Pollution

Historically, Environment Ontario and other North American jurisdictions have been dealing with contaminants as pollutants in their own right, concerned with their potential "localized" and "community" effects.

To aid in this activity, the Ontario Environment Ministry established a Province-wide Inventory of air contaminants in 1972, which includes sulphur dioxide. Concentrations of 30 known air-borne contaminants are measured by a monitoring network distributed throughout Ontario which consists of more than 1,400 air quality instruments, some of which are operated on a special study basis. This monitoring network was established to obtain comprehensive knowledge of the air quality in Ontario. The data has been related to emitting sources and, in association with air quality simulation models, has been used to develop control strategies for these sources when air quality criteria set by the Province were exceeded.

However, in dealing with the problem of total suspended particulates and the photochemical product such as ozone, the evidence indicated that a large contribution was attributable to out-of-the province sources. More recently, acidic precipitation studies indicated that the precursors SO_2 , sulphates and nitrates are due to sources which are in part

very distant from the sensitive receptor lakes.

The severity of this problem of long range transport in Ontario became apparent when we began to analyse the results from several special studies, in particular, the Sudbury Environmental and Lakeshore Capacity Studies. Both of these geographically intensive programs measured atmospheric pollutants and quantified the proportion which as a consequence of various physical and chemical means ultimately end up in sensitive terrestrial and aquatic ecosystems. As subsequent speakers will outline in detail, much has been learned from these studies about the ultimate fate of emissions of oxides of sulphur and particulates as well as other pollutants on a continental basis. In particular, these studies indicated that when using contemporary monitoring and analytical techniques, the secondary or evolutionary pollutants associated with primary emissions of particulates and SO_2 were being deposited in large measure by the rain falling over large portions of the Province. Furthermore, this polluted rain was and is seriously affecting Ontario's very sensitive environment.

In response to the seriousness of this situation and recognizing its similarity with the Scandinavian problem, the Ontario Government initiated a major long range transport of atmospheric pollutants or "acidic precipitation" program in 1979. Currently this program has a budget in excess of six million dollars per year which is of the order of \$1.00 per

capita per year.

The major elements of this effort include the following, undertaken in parallel:

1. a scientific LRTAP/ACID Rain assessment program;
2. socio-economic initiatives;
3. control technology investigations;
4. information dissemination and public education program;
5. policy evaluation, recommendation and implementation.

The scientific program is broken down into the following specific components.

- a) Cooperative international programs such as DOAPS (Detroit/Ontario Air Pollution Study), O₂SCAR (Oxidation and Scavenging Characteristics of April Rains), the Quetico Park initiative, and PEPE (Prolonged Elevated Pollution Episodes). The common objective of these studies is to track and quantify the deposition of transboundary pollutants from source to receptor;
- b) detailed atmospheric chemistry studies, in particular the Nanticoke and Sudbury area plume washout studies;
- c) wet and dry deposition monitoring networks on a provincial scale. Every effort has been made to integrate these with Canadian and U.S. networks;
- d) investigative studies of both the aquatic and terrestrial effects of the long range transport of

air pollutants;

- e) development and calibration of atmospheric transport models, which tie together all the information generated by the previously mentioned four points.

The socio-economic initiatives are investigating the various socio-economic consequences of various policy options and includes detailed investigation of appropriate methodologies as they relate to Ontario's recreational industry.

The Control technology investigations are exploring and evaluating the feasibility of different forms of abatement options including:

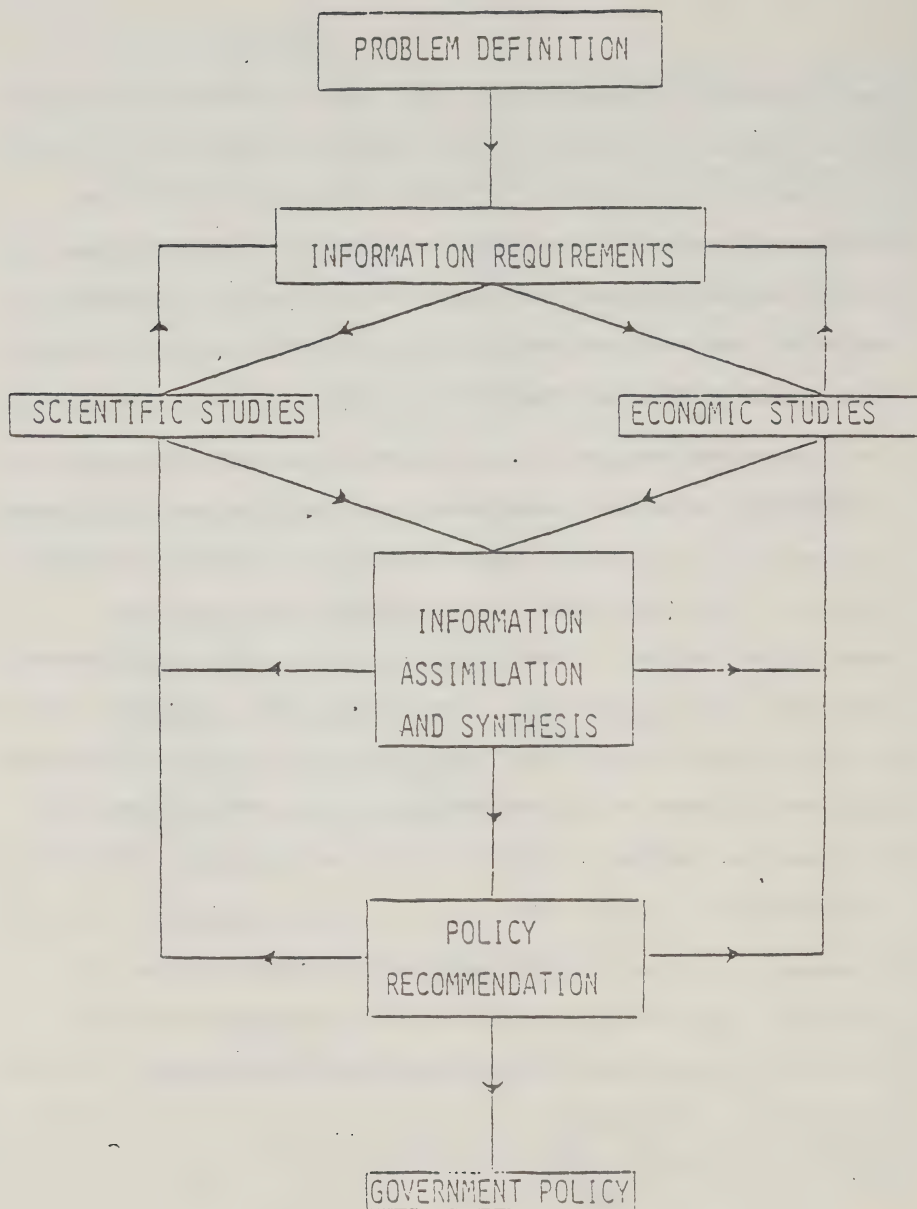
- Fluidized Bed Combustion
- Flue Gas Desulphurisation
- Limestone Injection Multistage Burner
- Use of Low Sulphur Coal
- Physical Coal Cleaning
- Oil Cleaning
- Hydrometallurgy
- Improved Pyrrhotite Separation
- Acid Production
- Improved Particulate Collecting Devices

At this point it is instructive to note that this activity is closely integrated with the source - receptor - effects modelling activity. It underlines the importance of modelling for expeditiously and rationally developing an effective abatement program.

The information dissemination and public information program has as its major objective the marshalling of public support for Ontario's initiatives to limit emissions within the Province of Ontario. In addition, Ontario has produced various media packages with which to convey its message to the North American audience including brochures, videotapes, fact sheets and a feature length film.

The integrated results of all these activities are being utilized by Ontario's regulatory arm (eg. the decision-makers such as Mr. G. Scott) so that decision making has and will continue to be undertaken in a logical, step-wise and expeditious manner to deal with this and other environmental problems. It is important to note that this "dynamic" activity which utilizes information from scientific and socio-economic programs is immediately responsive to any new information. The positive feedback aspect of this activity is systematically illustrated in (Figure One).

In summary, I have quickly outlined how Ontario came to recognize the problem of the long range transport of air pollutants, the studies that have been initiated as a result, and how this information is and will continue to be used to aid in policy decisions.



Lou Shenfeld

CASE STUDIES OF TRANSBOUNDARY AIR
POLLUTION: THE DEVELOPMENT OF EVIDENCE

DR. WALTER LYONS HAS ILLUSTRATED THE METEOROLOGICAL CONDITIONS THAT ARE CONDUCIVE TO THE LONG RANGE TRANSPORT OF AIR POLLUTANTS OVER EASTERN NORTH AMERICA. I AM GOING TO PRESENT QUANTITATIVE EVIDENCE OF THE RESULTS OF SUCH TRANSPORT AND THE IMPACT THAT THIS HAD ON PENNSYLVANIA, NEW YORK AND SOUTHERN ONTARIO.

THESE STUDIES HAVE BEEN USED BY OUR MINISTRY TO ASSESS THE RELATIVE IMPORTANCE OF ONTARIO'S SOURCES FOR THE PURPOSE OF REGULATION, AND I FEEL THAT THE RESULTS ALSO SUPPORT AND CONFIRM THE WORK OF DR. PARRY SAMSON REGARDING THE IMPACT OF TRANSBOUNDARY POLLUTION IMPACT IN NEW YORK AND PENNSYLVANIA.

ONE CASE THAT I WILL DESCRIBE IN DETAIL OCCURRED DURING THE PERIOD OF FEBRUARY 19 to 21, 1979. THE SERIES OF WEATHER MAPS FOR EARLY MORNING OF EACH OF THESE DAYS SHOWS THE LOCATION OF A HIGH PRESSURE AREA THAT WAS CENTRED SOUTH OF THE GREAT LAKES (FIG. 1) ON THE 19th, AND MOVED EASTWARD TO THE EAST COAST ON THE 20th. (FIG. 2). BEHIND THE HIGH WAS A PRONOUNCED SOUTHWESTERLY CIRCULATION. A LOW PRESSURE AREA MOVED INTO THE GREAT LAKES AREA ON THE 21st. (FIG. 3).

PRIOR TO THE 19th, SOUTHERN ONTARIO AND GREAT LAKES STATES WERE UNDER THE GRIP OF A PROLONGED COLD SPELL. THE COLD WEATHER WOULD CAUSE A HIGH ENERGY DEMAND FOR HEATING, RESULTING IN HIGHER THAN NORMAL EMISSIONS OF SULPHUR DIOXIDE AND PARTICULATE MATTER IN THE AREA.

AS SHOWN BY THE RADIOSONDE REPORTS FOR FLINT, MICHIGAN, (FIG. 4), THE AIRMASS OVER GREAT LAKES REGIONS ON THE 19th AND 20th WAS VERY STABLE WITH AN INTENSE INVERSION FORMING A STRONG LID ON THE UPWARD DISPERSION OF POLLUTANTS AT AN ALTITUDE OF APPROXIMATELY 500 METRES. THIS LIMITED MIXING HEIGHT PROVIDED THE CONDITIONS FOR THE EXTENDED TRANSPORT OF POLLUTANTS IN HIGH

CONCENTRATIONS INTO AND ACROSS ONTARIO.

AS SOUTHWESTERLY WINDS BACK OF THE HIGH PRESSURE AREA BECAME ESTABLISHED, SULPHUR DIOXIDE LEVELS AT THE MONITORING STATIONS INCREASED ACROSS THE ENTIRE MONITORING NETWORK. SEE FIG 5. THE CHANGE IN LEVELS CAN BE SEEN FROM THE 24-HOUR AVERAGE LEVELS LISTED FOR THE 19th, 20th AND 21st. (TABLES 1a AND 1b). IN ONTARIO THE LEVELS RANGED FROM NON-DETECTABLE TO A MAXIMUM AVERAGE OF 60 ppb ON THE 19th, WHILE ON THE 20th THE AVERAGE LEVELS WERE MUCH HIGHER, EXCEEDING 100 ppb AT A FEW LOCATIONS. ONTARIO'S CRITERION FOR DESIRABLE AIR IS 100 ppb OF SO_2 FOR A DAILY AVERAGE AS COMPARED TO THE U.S. STANDARD OF 140 ppb FOR A 24-HOUR RUNNING AVERAGE. THE EVIDENCE OF THE LONG RANGE TRANSPORT OF SO_2 IS CLEARLY INDICATED BY THE MEASUREMENTS AT RURAL STATIONS. INVERHURON ON THE SHORE OF LAKE HURON RARELY RECORDS HOURLY LEVELS ABOVE 20 ppb BUT ON THE 20th RECORDED A 24-HOUR AVERAGE OF 40 ppb. THE RURAL SIMCOE STATION LOCATED NORTH OF LAKE ERIE RECORDED A 24-HOUR AVERAGE OF 70 ppb. THERE ARE NO SIGNIFICANT LOCAL SOURCES OF SULPHUR DIOXIDE IN THE SOUTHWEST DIRECTION, THAT IS THE DIRECTION UPWIND OF THESE STATIONS ON FEBRUARY 20th, AS INDICATED BY THE BACK - TRAJECTORIES FOR THAT DAY FOR THOSE LOCATIONS (FIGURE 6). BACK TRAJECTORIES WHICH ARE THE ESTIMATED LOCATIONS OF PARCELS OF AIR IN 6 HOUR STEPS UP TO 1 A.M. LOCAL TIME IN THE MORNING OF THE 19th, 20th, 21st ARE SHOWN FOR OTHER LOCATIONS IN FIGURES 7, 8 AND 9. THESE TRAJECTORIES CLEARLY SHOW THE AIR PARCELS ORIGINATING IN THE NEIGHBORING STATES.

TOTAL SUSPENDED PARTICULATE MATTER (TSP) WHICH ARE MONITORED EVERY SIXTH DAY, WERE MONITORED ON FEB. 20th. THE LEVELS OF TSP AND THE SULPHATE COMPONENT WERE VERY MUCH ABOVE NORMAL FOR BOTH

RURAL AND URBAN STATIONS ACROSS THE AREA. (TABLES 2A and 2B.) FOR A DAILY MEASUREMENT OF TSP, ONTARIO'S CRITERION FOR DESIRABLE AIR IS 120 ug./m^3 . THIS WAS EXCEEDED AT SEVERAL LOCATIONS. THE CONSISTENT HIGH SULPHATE COMPONENT WHICH IS INDICATIVE OF LONG RANGE TRANSPORT AVERAGED ABOUT 30% OF THE TSP MEASURED AT ONTARIO LOCATIONS. REDUCED VISIBILITIES HAVE BEEN RELATED TO HIGH SULPHATE CONCENTRATIONS.^{1,2} THE U.S. - E.P.A REPORT, "VISIBILITY IN THE NORTHEAST"² CONCLUDED "THAT THE MAIN CONTRIBUTOR TO HAZE IN THE NORTHEAST IS SULPHATE, WHICH TYPICALLY ACCOUNTS FOR APPROXIMATELY 50% OF THE TOTAL EXT INCTION." VISIBILITIES AT ONTARIO AIRPORTS WERE ABOUT 15 MI. ON THE AFTERNOON OF THE 19th WHILE ON THE AFTERNOON OF THE 20th, THE REPORTED VISIBILITIES WERE 6 MI. AND LESS. TABLE 3 SHOWS THE VISIBILITIES AT SOME LOCATIONS IN PENNSYLVANIA AND NEW YORK.

ONTARIO'S AIR POLLUTION CONTROL LEGISLATION³ INCLUDES A REGULATORY SYSTEM THAT ALLOWS THE GOVERNMENT CONTROL AGENCY TO ORDER OWNERS OF SIGNIFICANT EMITTERS OF SULPHUR DIOXIDE AND/OR PARTICULATE MATTER TO CURTAIL THEIR EMISSIONS DURING HIGH POLLUTION POTENTIAL CONDITIONS. ALERTS ARE ISSUED ON THE BASIS OF WEATHER FORECASTS AND ONTARIO'S AIR POLLUTION INDEX (API) WHICH IS A FUNCTION OF THE 24-HOUR RUNNING AVERAGES OF SULPHUR DIOXIDE AND SUSPENDED PARTICULATE MATTER MEASURED IN TERMS OF THE COEFFICIENT OF HAZE. AN API OF LESS THAN 32 IS CONSIDERED ACCEPTABLE. AT THESE LEVELS CONCENTRATIONS OF SO_2 AND TSP SHOULD HAVE LITTLE OR NO EFFECT ON HUMAN HEALTH. AT THE ADVISORY LEVEL OF 32, WITH METEOROLOGICAL CONDITIONS FORECAST TO REMAIN ADVERSE FOR SIX HOURS, SIGNIFICANT SOURCES OF POLLUTION IN THE COMMUNITY IN WHICH A HIGH API OCCURS ARE REQUESTED TO CURTAIL

OPERATIONS. THE SYSTEM IS DESIGNED WITH THE OBJECTIVE OF PREVENTING THE API FROM REACHING A LEVEL OF 57 IN ANY ONTARIO COMMUNITY. AT THIS LEVEL, RESEARCH BY DR. P.J. LAWTHOR⁴ INDICATED THAT HIS PATIENTS WITH CHRONIC RESPIRATORY DISEASE WERE NOTED TO EXPERIENCE AN ACCENTUATION OF SYMPTOMS. EVIDENCE OF THE RELATIONSHIP OF THE API AND HEALTH WERE REPORTED BY LEVY ET AL⁵ WHO RELATED THE API WITH INCREASING HOSPITAL ADMISSIONS FOR ACUTE EXACERBATIONS AMONG ADULTS WITH CHRONIC RESPIRATORY ILLNESS AND CHILDREN WITH ACUTE RESPIRATORY DISEASE.

DURING THE INCIDENT OF FEBRUARY 19 - 21, THE API EXCEEDED 32 IN THREE ONTARIO CITIES WHERE SIGNIFICANT SOURCES WERE REQUESTED TO CURTAIL EMISSIONS. SARNIA IN THE SOUTHWEST, FIRST TO EXCEED 32 AT 10:00 A.M. OF THE 20th, REACHED A MAXIMUM AT 43 AT 3:00 P.M. OF THAT DAY. HAMILTON AND TORONTO API EXCEEDED 32 AT 4:00 A.M. AND 6:00 A.M. OF THE 21st REACHING MAXIMUM LEVELS OF 34 AND 33 RESPECTIVELY. THE INCIDENT IS OF INTEREST IN THAT ALTHOUGH A SIGNIFICANT CONTRIBUTION TO POLLUTANT LEVELS, ESTIMATED AT APPROXIMATELY 50%, ORIGINATED IN UNITED STATES, CANADIAN SOURCES HAD TO BEAR THE COST OF CURTAILING EMISSIONS TO PREVENT ADDITIONAL AIR QUALITY DETERIORATION AND POSSIBLE HEALTH EFFECTS.

WHILE WE HAVE DESCRIBED IN DETAIL ONE POLLUTION INCIDENT OF THE LONG RANGE TRANSPORT OF POLLUTANTS, THIS IS NOT AN ISOLATED CASE. SULPHUR DIOXIDE WAS SHOWN TO HAVE BEEN TRANSPORTED INTO SOUTHERN ONTARIO ON JANUARY 24, 1977. A RURAL STATION NORTH OF LAKE ERIE RECORDED 24-AVERAGE CONCENTRATION ABOVE ONTARIO'S CRITERION.⁶ THERE ARE IN THE SCIENTIFIC LITERATURE MANY DOCUMENTED ACCOUNTS TO THE TRANSPORT OF POLLUTANTS SUCH AS SULPHATES, NITRATES AND OZONE.^{7,8,9,10,11}

THE STUDIES FOR THE NORTHEASTERN UNITED STATES AND ONTARIO OFTEN SHOW THEIR OCCURRENCE TO BE DIRECTLY RELATED WITH THE BACK-OF-THE-HIGH SOUTHWESTERLY CIRCULATION OF STABLE AIR.

FOR THE RECEPTOR AREAS OF NEW YORK, PENNSYLVANIA AND ONTARIO THIS AIR FREQUENTLY FIRST PASSES THROUGH THE INDUSTRIALIZED OHIO VALLEY THAT HAS MANY OF THE LARGE COAL-FIRED POWER PLANTS REQUESTING A RELAXATION OF STANDARDS. FIFTEEN MAJOR INCIDENTS OF HIGH SULPHATES SUCH AS THAT WHICH HAS BEEN DESCRIBED BY DR. LYONS FOR THE PERIOD AUGUST 16 to 28, 1976, OCCURRED DURING THE PERIOD OF 1976 - 1980.

I WOULD NOW LIKE TO TOUCH ON THE TRANSPORT OF OZONE, INTO THE NEW YORK - PENNSYLVANIA - ONTARIO AREA, BECAUSE OZONE IS BELIEVED TO BE A PROMOTER OF SO_2 OXIDATION TO SULFATE AND RESULTANT HAZE FORMATION.

DURING THE SUMMER ONTARIO OBSERVES THAT AIR MASSES FROM THE SOUTH CONTAINS OZONE AS WELL AS SULPHATES. OZONE LEVELS IN BOTH RURAL AND URBAN AREAS OFTEN EXCEED 80 ppb, the ONTARIO CRITERION FOR DESIRABLE AIR AS WELL AS THE U.S. - E.P.A. STANDARD OF 120 ppb. FIGURE 10 SHOWS THE LOCATION OF ONTARIO'S OZONE MONITORING STATIONS. AS CAN BE SEEN FROM TABLE 4. THE HOURLY AVERAGE OZONE LEVELS HAVE EXCEEDED 200 ppb, THE FIRST ALERT LEVEL IN THE BAY AREA OF CALIFORNIA. THE NUMBER OF EPISODE DAYS THAT OZONE EXCEEDED ONTARIO'S CRITERION AT LEAST ONE OF THE MONITORING STATIONS IN OPERATION SINCE 1978 RANGE FROM 43 IN 1978 TO 14 IN 1979 AND 1980. FROM MAY 15 to SEPTEMBER 15 WHEN ELEVATED LEVELS OF OZONE MAY BE EXPECTED IN ONTARIO, THE CRITERION WAS

EXCEEDED ON 110 DAYS OR ALMOST 20% OF THE TOTAL NUMBER OF DAYS DURING THE 5 YEAR PERIOD OF 1976 TO 1980.

BACK - TRAJECTORIES OF AIR PARCELS SHOW THAT ON A CONSISTANT BASIS AIR ARRIVING IN SOUTHERN ONTARIO WITH A HIGH SULPHATE AND/OR OZONE CONTENT AND POOR VISIBILITY ORIGINATES SOUTH OF THE GREAT LAKES.⁸ THE RESULTS ARE SIMILAR TO THAT REPORTED FOR NEW YORK STATE⁹ THAT INDICATED COMPARATIVELY CLEAN AIR TO BE ASSOCIATED WITH A NORTHERLY CIRCULATION AND CONTAMINATED AIR WITH POOR VISIBILITIES WITH CIRCULATIONS FROM THE SOUTHWEST. IN THE SUMMER, IT IS A COMBINATION OF SULPHATES AND OZONE THAT ARRIVES WITH A SOUTHERLY CIRCULATION AND REDUCES VISIBILITY. IN THE WINTER, SULPHUR DIOXIDE AND PARTICULATE MATTER WITH A HIGH COMPONENT OF SULPHATES HAVE BEEN NOTED TO BE ASSOCIATED WITH THIS AIR MASS ORIGINATING SOUTH OF US.

ANOTHER IMPACT OF TRANSPORTED POLLUTANTS OTHER THAN A REDUCTION IN VISIBILITY OCCURS AS A RESULT OF THEIR DEPOSITION FROM THE ATMOSPHERE. HERE AGAIN BACK TRAJECTORY ANALYSES WERE USED TO DETERMINE THE SOURCE AREA OF SUCH IMPACT. DATA FROM PRECIPITATION COLLECTORS OPERATED IN THE MUSKOKA - HALIBURTON AREA OF SOUTH - CENTRAL ONTARIO FOR ALMOST A 3 YEAR PERIOD, COMBINED WITH BACK - TRAJECTORY ANALYSES, SHOWED THAT ABOUT 75% OF THE PRECIPITATION EVENTS AND MOREOVER APPROXIMATELY 80% OF THE WET ACID DEPOSITION AT THE SITE WERE ASSOCIATED WITH AIR MASSES ARRIVING FROM THE SOUTH AND SOUTHWEST. COMPARATIVELY A SMALL PERCENTAGE OF THE LOADINGS CAME FROM THE NORTH AND NORTHWEST WHERE SUDBURY SMELTERS ARE LOCATED.

I MENTION THIS STUDY AS ANOTHER PIECE OF EVIDENCE WHICH WE USED IN CONSIDERING THE CONTROL OF ONTARIO SOURCES.

MORE GENERALLY, ALL THE BACK - TRAJECTORY STUDIES I HAVE DISCUSSED LIKE THOSE OF DR. PARRY SAMSON, ILLUSTRATE CLEARLY THE SIGNIFICANT TRANSPORT OF POLLUTANTS INTO NEW YORK, PENNSYLVANIA AND ONTARIO. WE FEEL THAT IT IS TIME EPA TAKES A POSITIVE ROLE IN CONTROLLING THESE TRANSBOUNDARY POLLUTION PROBLEMS.

FIG. 1 MONDAY, FEBRUARY 19, 1979

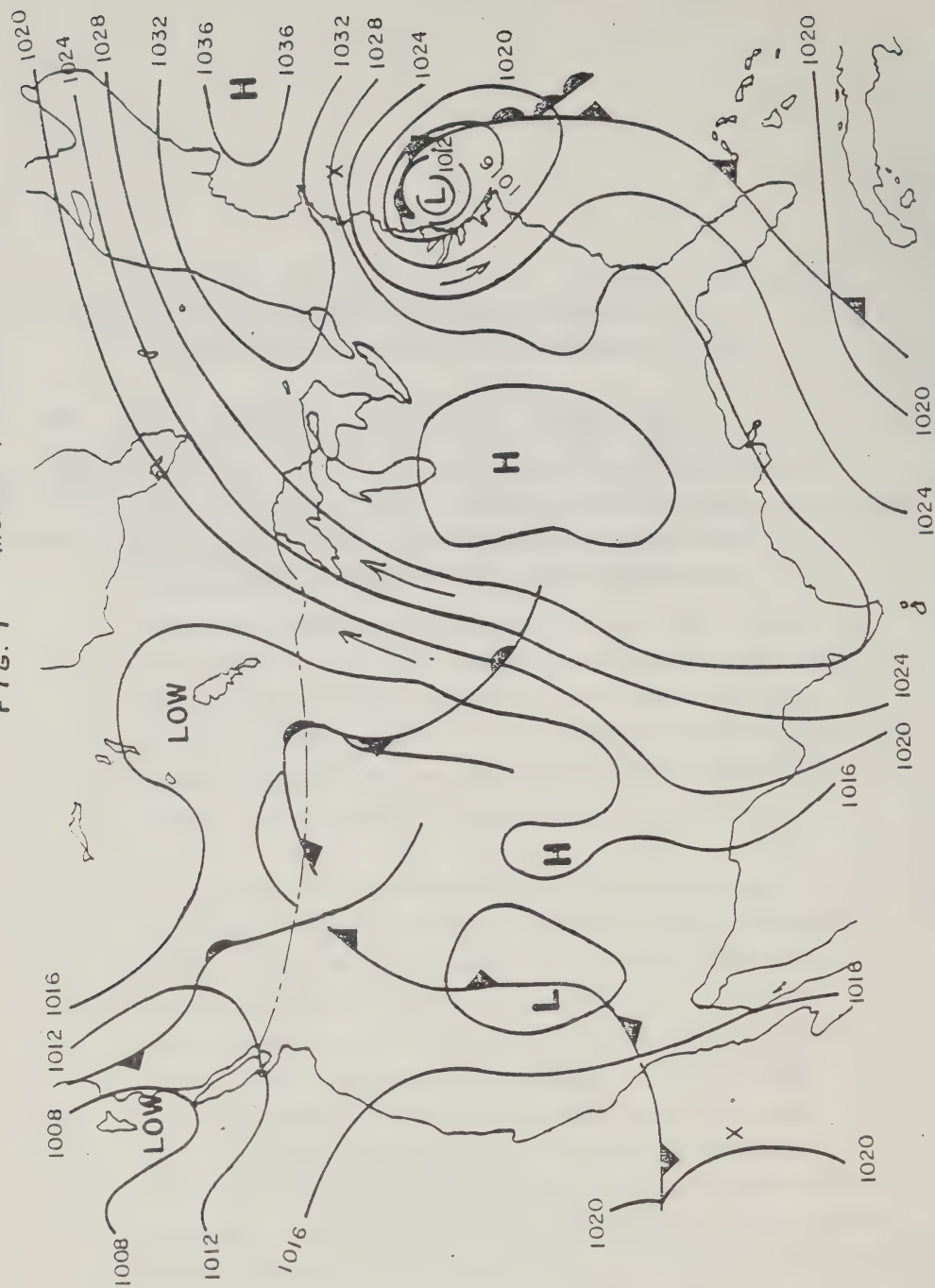


FIG. 2 TUESDAY, FEBRUARY 20, 1979

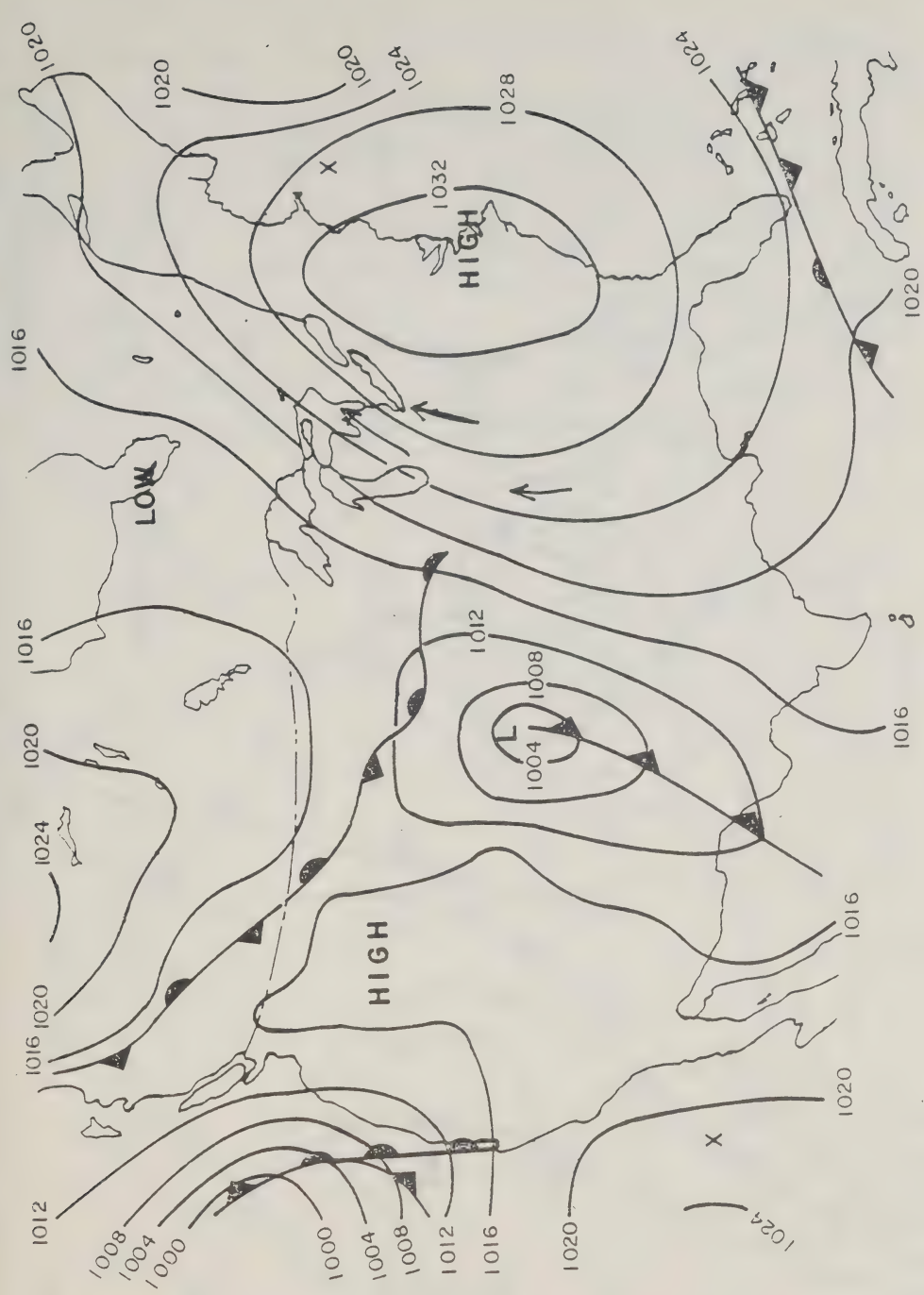


FIG. 3 WEDNESDAY, FEBRUARY 21, 1979

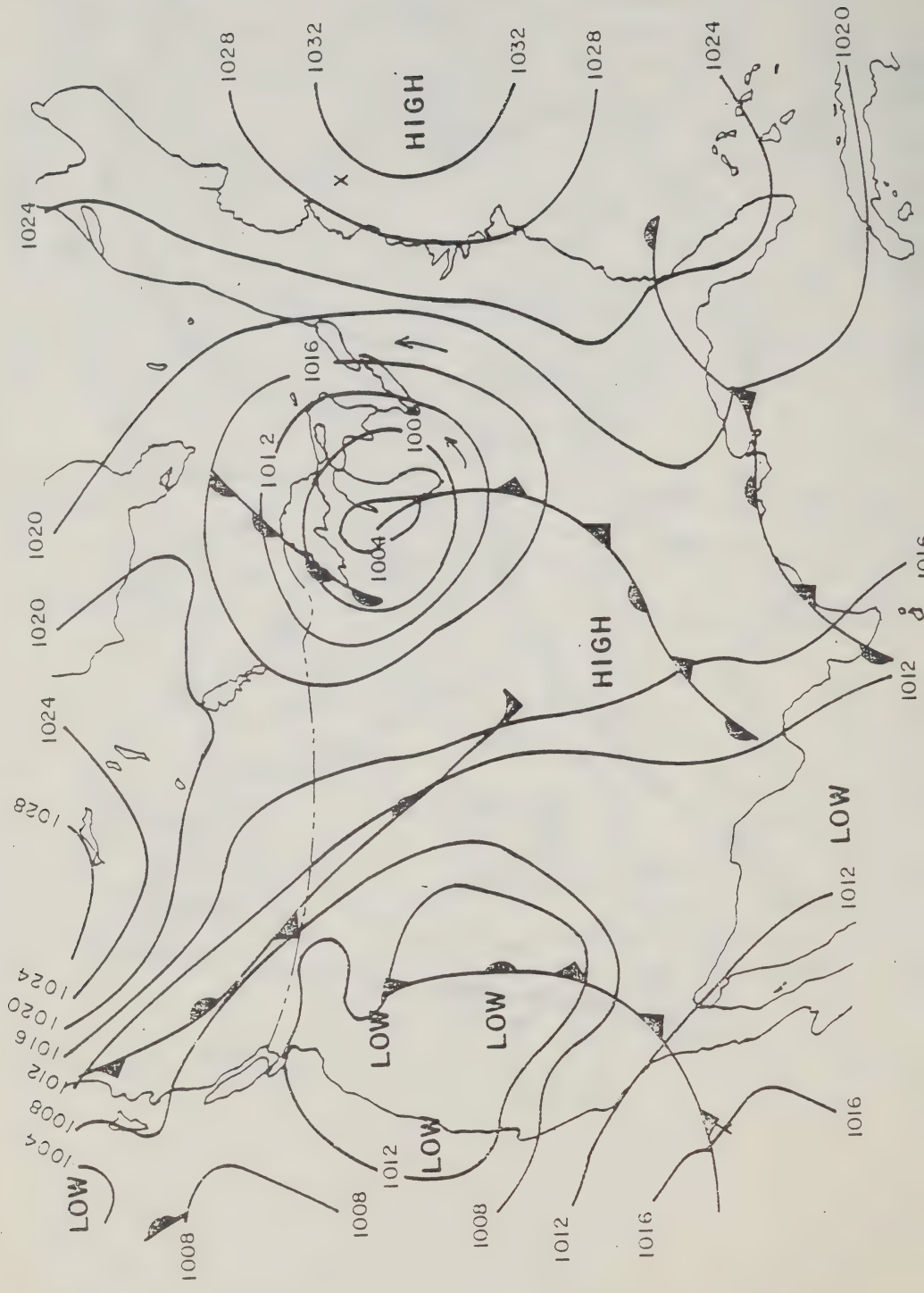
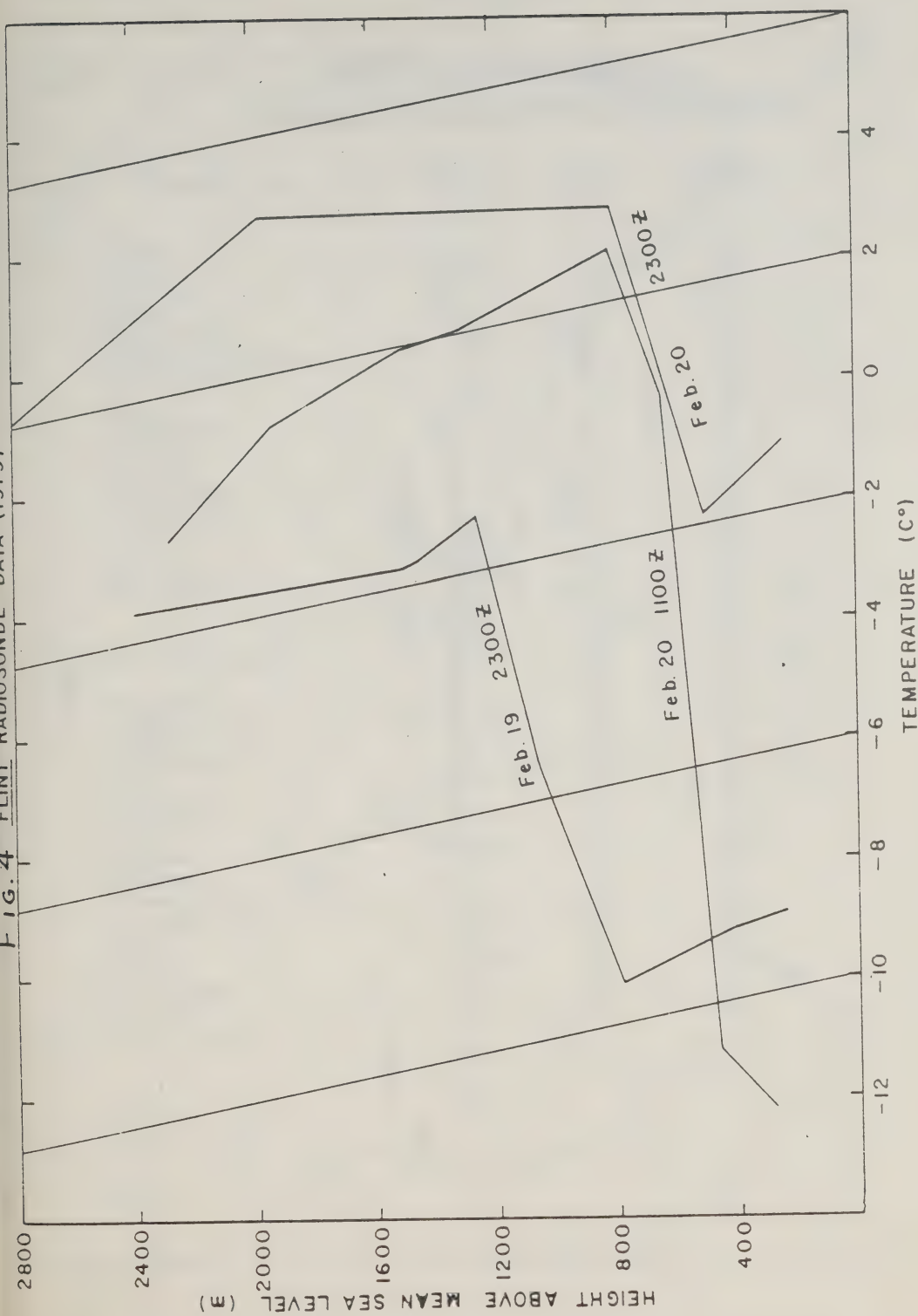


FIG. 4 FLINT RADIOSONDE DATA (1979)



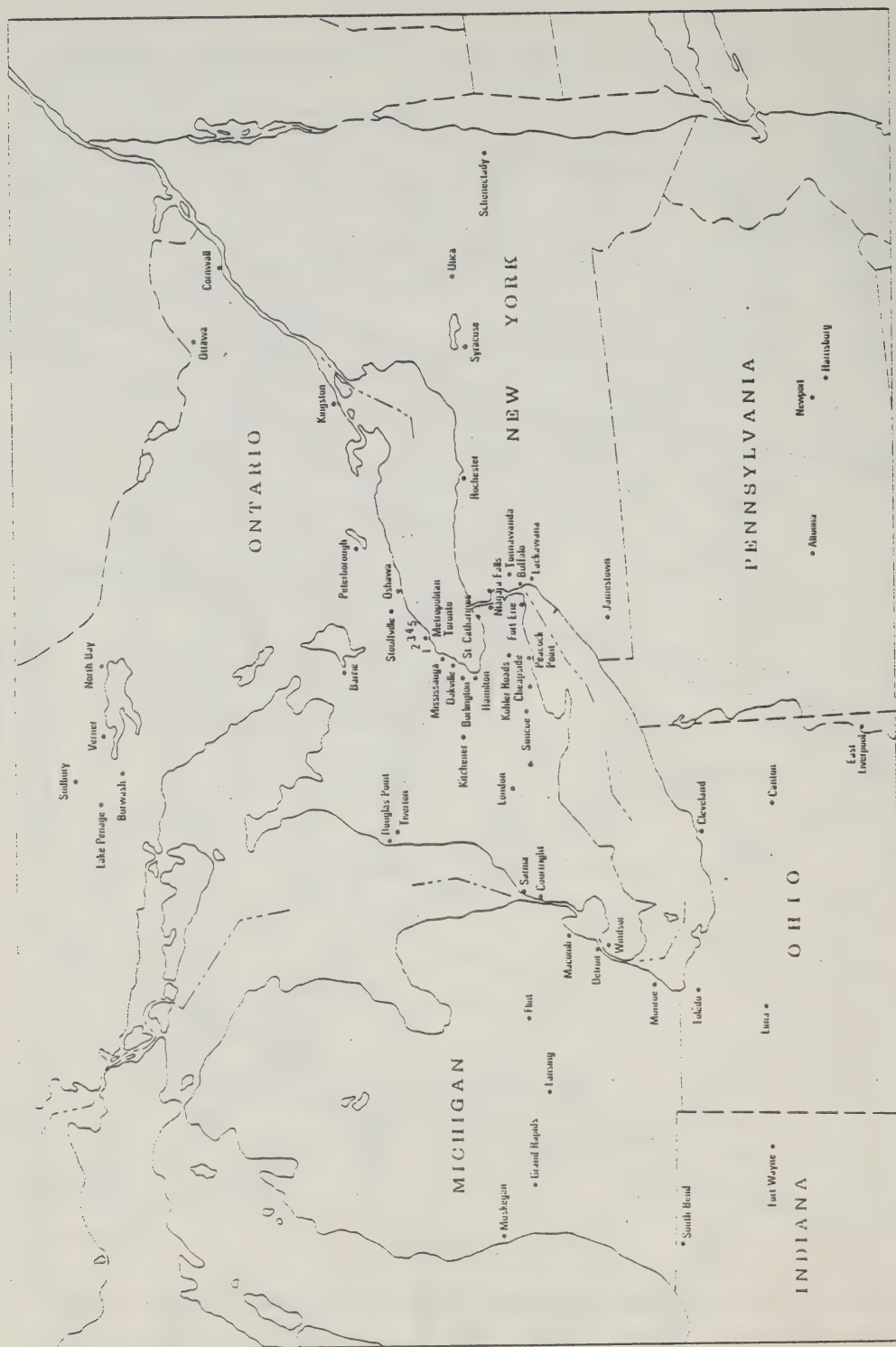


FIG. 5. Map Showing Locations of Monitoring Stations.

TWENTY-FOUR HOUR AVERAGESULPHUR DIOXIDE CONCENTRATIONS (ppb) 1979

<u>Location</u>	<u>19 Feb</u>	<u>20 Feb</u>	<u>21 Feb</u>
Windsor	60	80	40
Sarnia	60	130	40
Courtright	30	70	40
London	20	50	30
Douglas Point	11	53	33
Inverhuron (Tiverton)	10	40	20
Peacock Point	22	59	31
Simcoe	-	70	50
Kohler Road	24	61	49
Cheapside	0	60	40
Kitchener	10	40	30
Niagara Falls	20	50	40
St. Catharines	20	50	30
Ft. Erie	10	70	40
Hamilton	20	50	50
Metro Toronto	30	80	40
(1)	45	106	28
(2)	40	110	30
(3)	20	60	30
(4)	20	50	30
(5)	30	40	50
Burlington	10	60	40
Oakville	30	100	50
Oshawa	30	50	20
Mississauga	20	50	50
Barrie	0	40	30
Stouffville	20	70	50
Ottawa	50	60	70
Cornwall	11	44	23
Kingston	10	50	30
Peterborough	10	40	40
North Bay	10	40	40
Verner	20	40	30
Sudbury	0	20	20
Lake Penage	0	30	40
Burwash			

Table

1(b)

TWENTY-FOUR HOUR AVERAGE

SULPHUR DIOXIDE CONCENTRATIONS (ppb) 1979 (cont'd)

<u>Location</u>	<u>19 Feb</u>	<u>20 Feb</u>	<u>21 Feb</u>
Jamestown, NY	14	49	37
Buffalo, NY (1)	49	102	41
(2)	28	75	44
Lackawanna, NY	40	82	41
Tonawanda, NY	33	107	51
Niagara Falls, NY	42	73	45
Rochester, NY	47	64	-
Utica, NY	21	43	33
Syracuse, NY (1)	26	49	34
(2)	19	42	29
Schenectady, NY	30	44	52
Altoona, Penn.	45	73	
Newport, Penn	15	34	
Harrisburg, Penn	34	72	
Bay County, Michigan	20	50	20
Flint, Michigan 30	50	20	
Lansing, Michigan	40	60	30
Grand Rapids, Michigan	40	60	20
Macomb County, Michigan	30	70	20
Monroe, Michigan	40	70	30
Muskegon, Michigan	30	70	40
Detroit, Michigan	20-40	50-100	10-30
Milan, Michigan	20	50	20

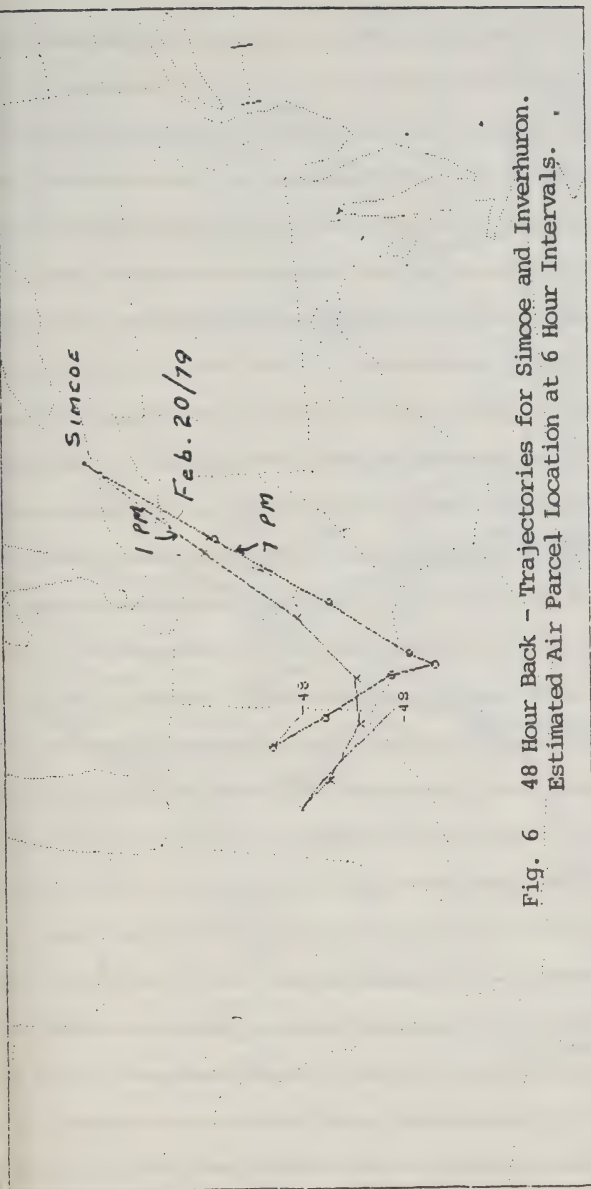
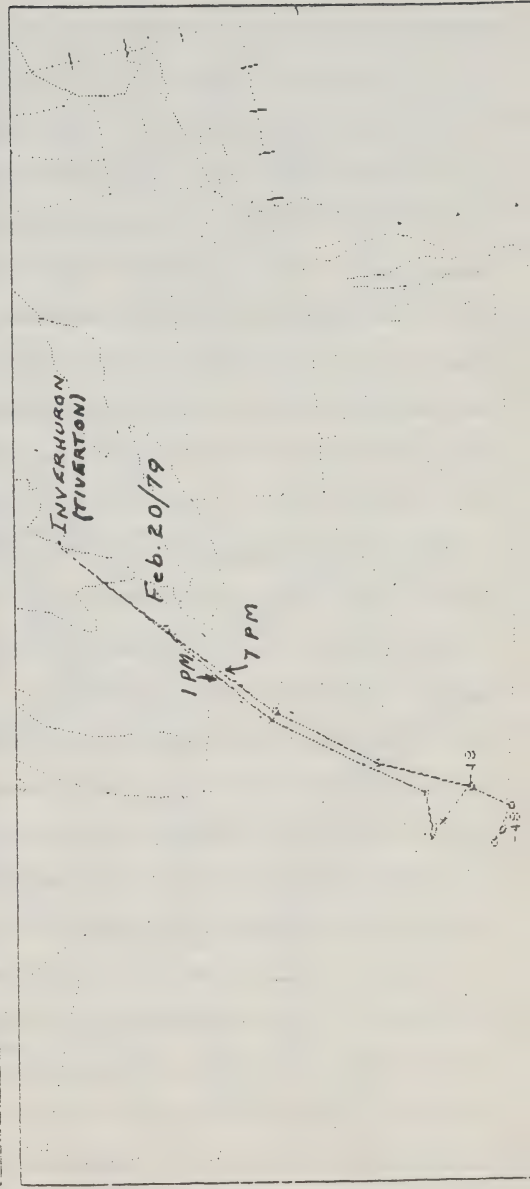
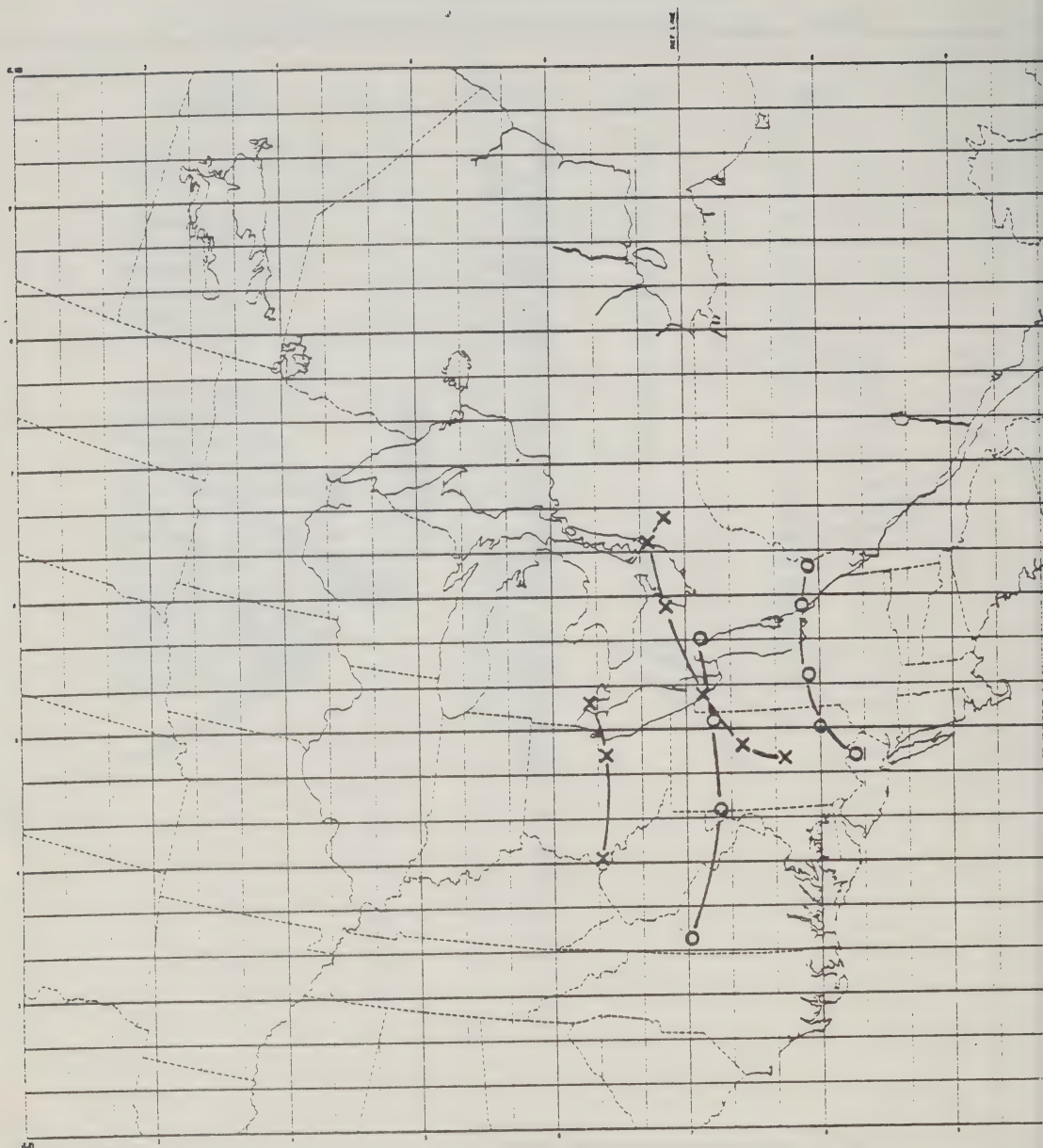


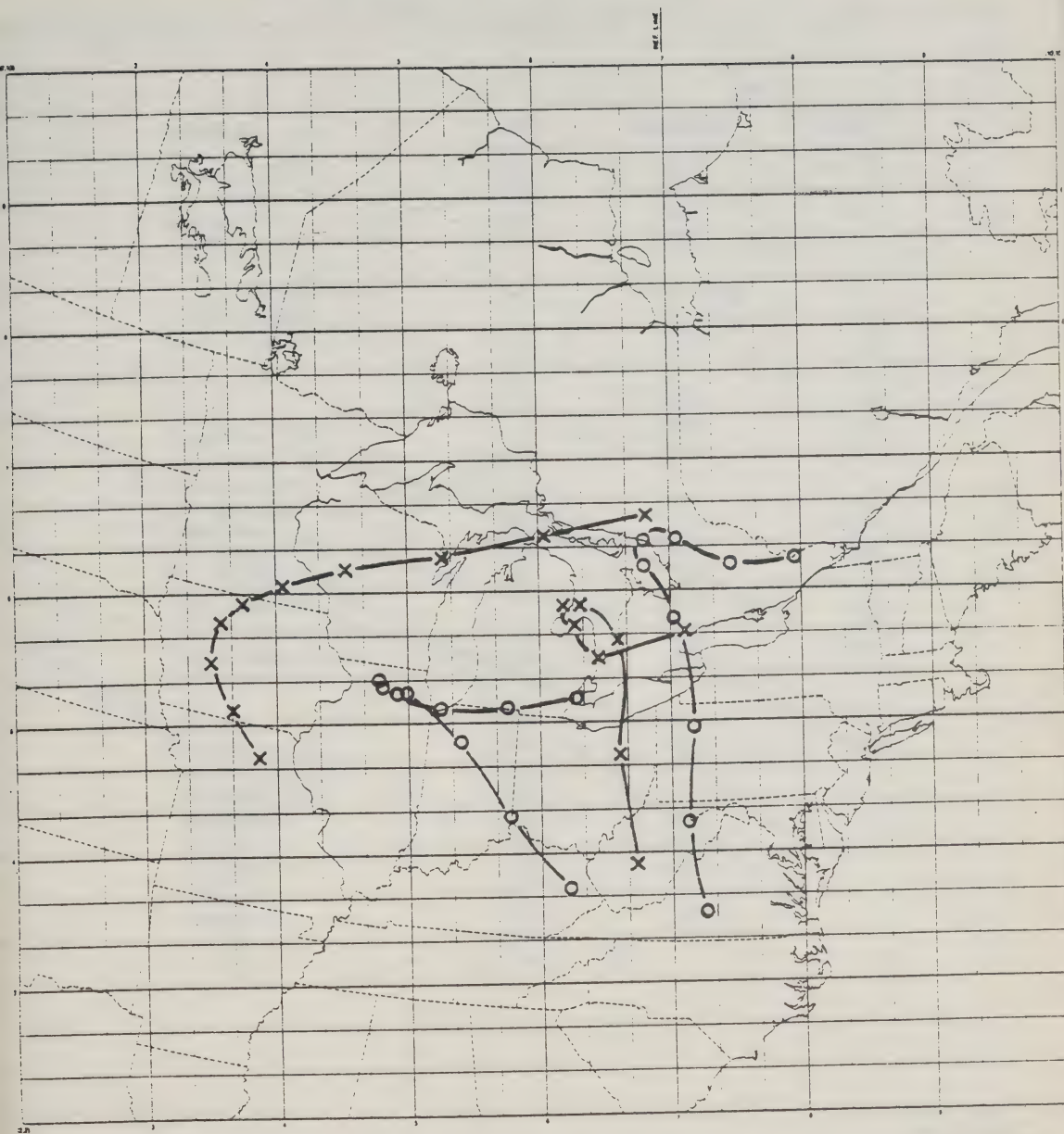
Fig. 6 48 Hour Back - Trajectories for Simcoe and Inverhuron.
Estimated Air Parcel Location at 6 Hour Intervals.





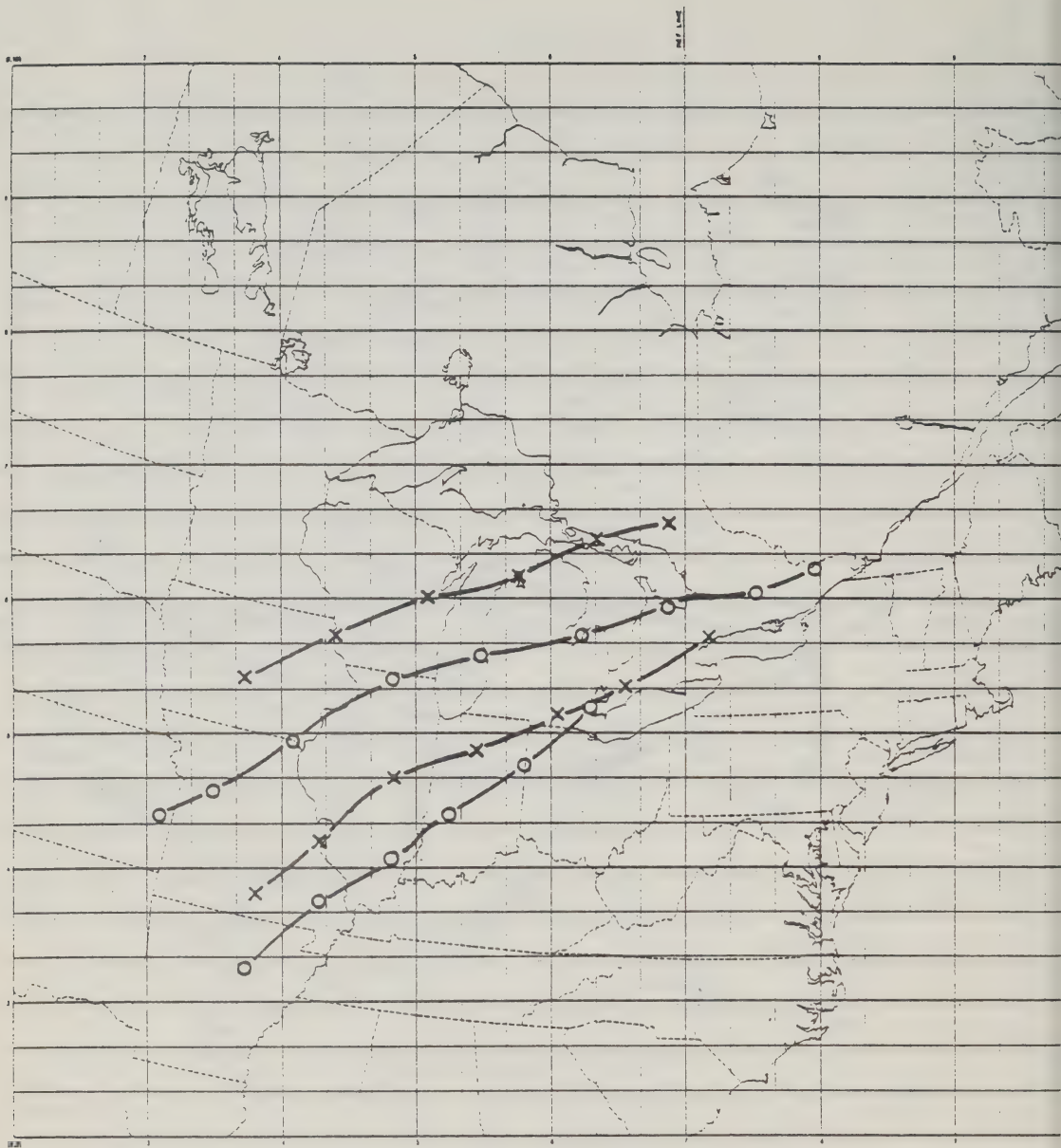
Back-trajectories showing Estimated Air Parcel locations at 6 hour intervals Terminating at 0100 EST
Feb. 19/79

FIG. 7



Back-trajectories showing Estimated Air Parcel locations at 6 hour intervals Terminating at 0100 EST
Feb. 20/79

FIG. 8



Back-trajectories showing Estimated Air Parcel locations at 6 hour intervals Terminating at 0100 EST
Feb. 21/79

FIG. 9

Table
2(a)

Concentrations of Total Suspended Particulate Matter,
Sulphate, and Nitrate ($\mu\text{g}/\text{m}^3$)
20 February 1979

<u>Location</u>	<u>TSP</u>	<u>Sulphate</u>	<u>Nitrate</u>
Windsor, Ont	141	34.5	10.9
Courtright, Ont.	132	41.0	4.6
Sarnia, Ont.	181	49.2	20.9
London, Ont.	92	30.7	4.2
St. Catharines, Ont.	83	28.5	4.5
Hamilton Ont.	117	34.5	4.3
Metro Toronto, Ont. (1)	116	33.8	7.0
(2)	144	28.3	13.3
(3)	77	25.5	5.9
(4)	134	34.0	10.7
Oakville, Ont.	113	35.0	4.2
Pickering, Ont.	147	35.3	8.2
Oshawa, Ont.	45	7.1	1.7
Mississauga, Ont.	95	23.3	6.3
Ottawa, Ont.	68	23.9	2.6
Belleville, Ont.	90	30.5	1.9
Brockville, Ont.	50	19.1	0.8
Cornwall, Ont.	93	25.6	5.7
Peterborough, Ont.	75	26.3	2.2
North Bay, Ont.	70	27.2	1.5
Sudbury, Ont.	56	24.7	2.9
Altoona, PA	96	36.8	-
Rochester, PA	201	31.8	-
Beaver Falls, PA	212	35.9	-
Monessen, PA	229	45.7	-
Donora, PA	285	51.2	-
Sharon, PA	201	32.8	-
Washington, PA	170	27.6	-
Erie, PA	63	18.3	-
Farrell, PA	91	19.9	-
Harrisburg, PA	116	29.0	-

Table
2(b)

CONCENTRATIONS OF TOTAL SUSPENDED PARTICULATE MATTER,
SULPHATE AND NITRATE (ug/m³)

20 FEBRUARY 1979

<u>Location</u>		<u>TSP</u>	<u>Sulphate</u>	<u>Nitrate</u>
Buffalo, NY	(1)	180	37.8	8.5
	(2)	85	21.0	2.5
Niagara Falls, NY		30	5.7	2.1
Jamestown, NY		57	19.6	0.6
Poughkeepsie, NY		91	19.6	5.8
Rochester, NY	(1)	75	20.1	2.8
	(2)	95	19.2	3.3
	(3)	79	19.4	3.1
	(4)	80	19.5	3.1
Utica, NY		69	17.9	3.7
Syracuse, NY		145	17.7	6.1
Troy, NY		52	17.8	1.0
Hamstead, Long Island, NY		101	18.5	8.6
Campbell, Ohio		182	47.9	15.5
Youngstown, Ohio		112-223	46.0	9.7
Canton, Ohio		74-184	22-42.4	10-17
Toledo, Ohio		88-130	28.9	8.4
Defiance, Ohio		52-67	18.2	18.9
Detroit, Michigan		106-288	-	-
Lansing, Michigan		69-91	-	-
Muskegon, Michigan		53-69	-	-
Grand Rapids, Michigan		96	-	-

TABLE 3

VISIBILITY IN MILES IN THE AFTERNOON OF FEB. 19 AND
FEB. 20/79

<u>LOCATION</u>	<u>FEB. 19</u>	<u>FEB. 20</u>
PITTSBURGH, PA.	10	5
BRADFORD	25	10
PHILLIPSBURGH	27	4
ALTOONA	7	5
BUFFALO, NY	12	7
ROCHESTER	10	7
BINGHAMPTON	25	7

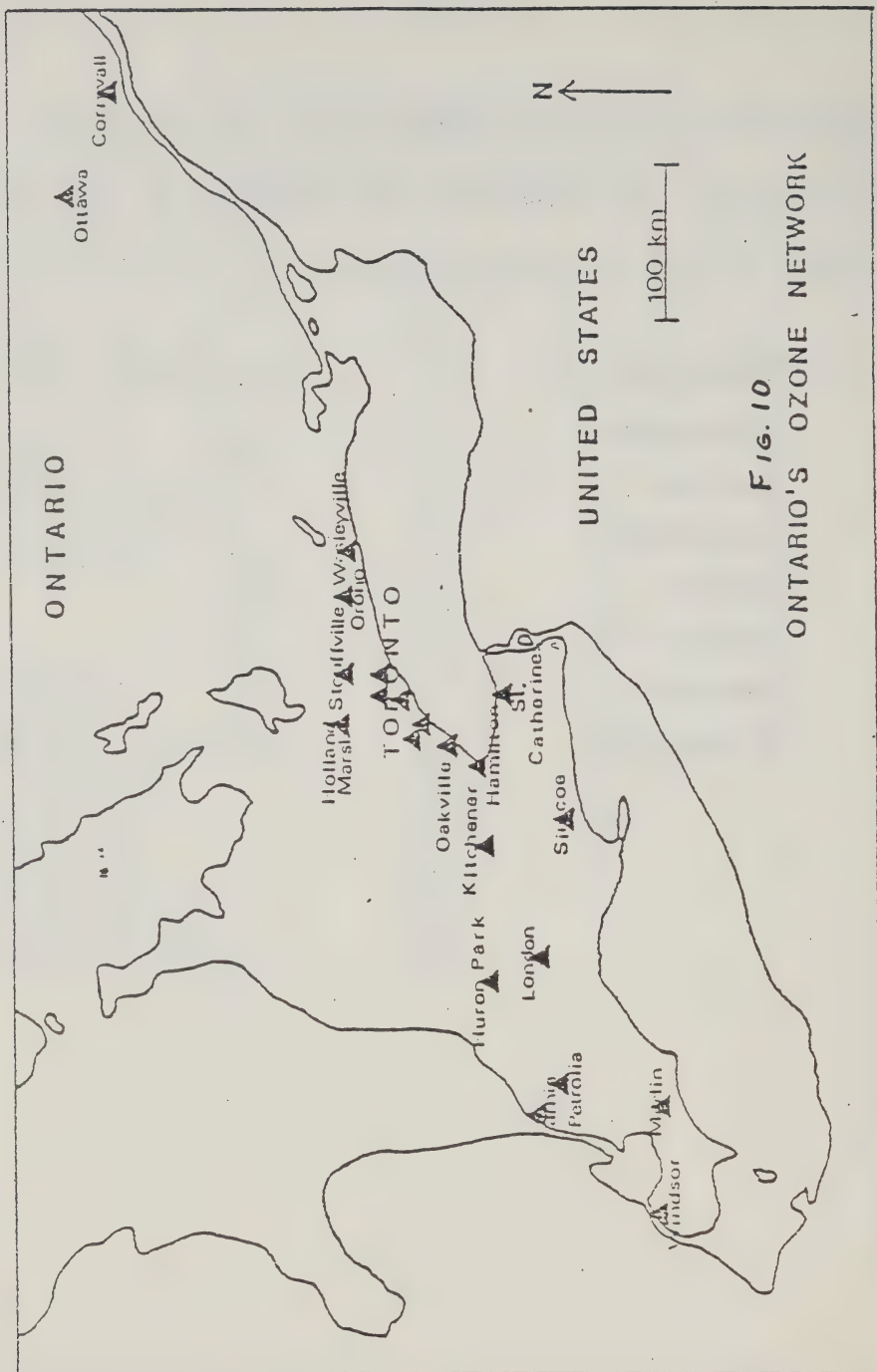


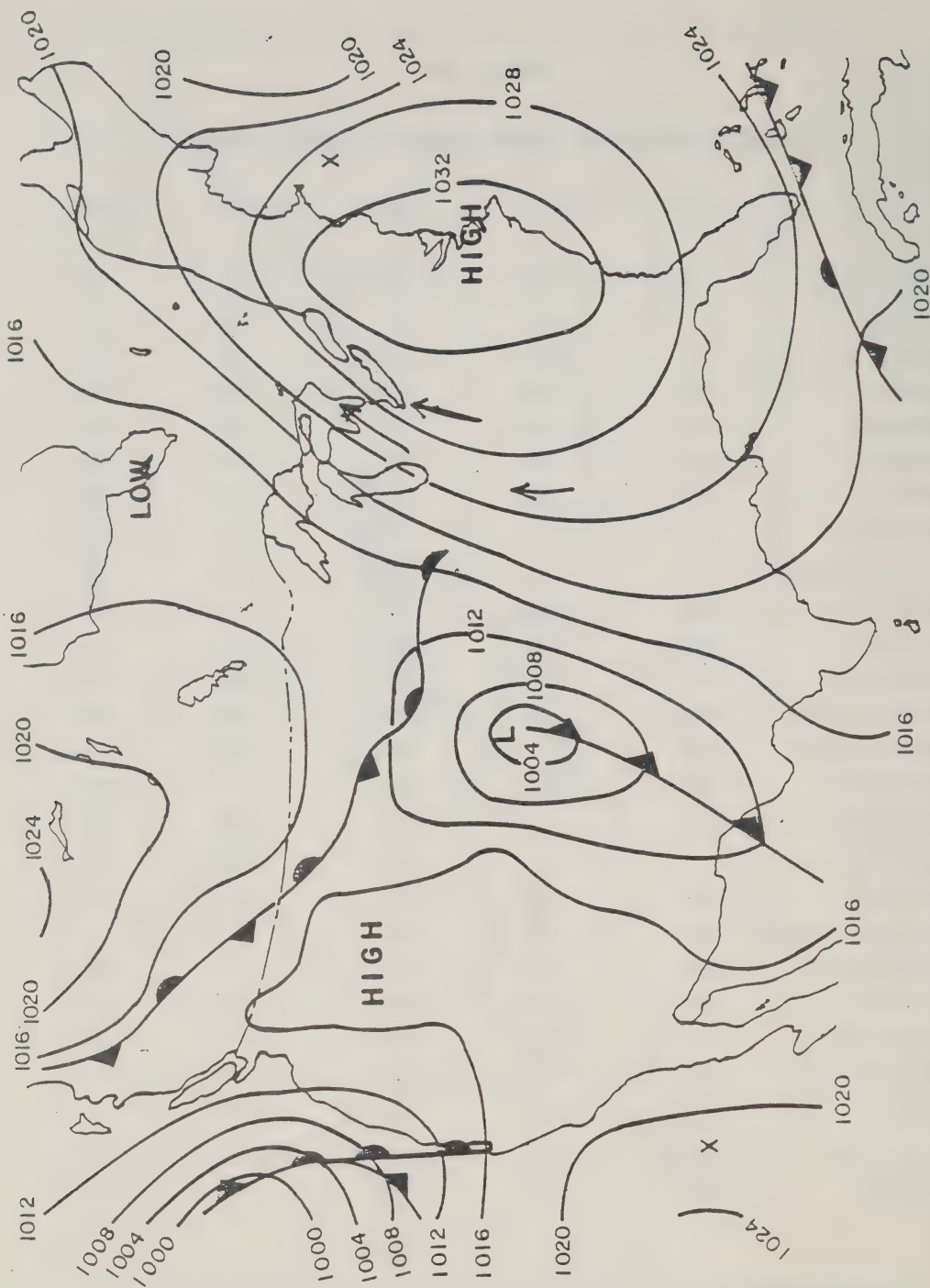
TABLE 4

MAXIMUM ONE HOUR OZONE CONCENTRATIONS (PPB)

	1976	1977	1978	1979	1980
HURON PARK	—*	137	134	123	120
WINDSOR	173	144	211	120	131
MERLIN	—	167	137	158	137
SARNIA	137	168	144	159	155
PETROLIA	—	146	148	148	125
LONDON	112	120	111	101	111
SIMCOE	139	133	171	148	99
KITCHENER	117	111	137	115	98
ST. CATHARINES	131	127	148	124	138
HAMILTON	128	93	119	112	107
TORONTO 1	138	110	135	155	121
TORONTO 2	—	—	102	106	77
SCARBOROUGH	142	107	128	165	108
NORTH YORK	139	—	140	99	125
ETOBICOKE 1	124	126	135	92	129
ETOBICOKE 2	106	111	116	126	107
MISSISSAUGA	—	—	129	134	120
OAKVILLE	124	122	142	129	109
HOLLAND MARSH	218	129	124	—	—
STOUFFVILLE	163	152	142	172	137
OTTAWA	96	91	133	96	83
CORNWALL	119	89	116	114	100
WESLEYVILLE	178	—	171	—	—
ORONO	162	176	181	149	—
ONTARIO	218	176	211	172	155

* - no data available.

FIG. 2 TUESDAY, FEBRUARY 20, 1979



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THE USE OF LAKE STUDIES IN MEASURING ATMOSPHERIC POLLUTION

T. BRYDGES

GOOD EVENING, MY NAME IS TOM BRYDGES. I AM THE SUPERVISOR OF THE LIMNOLOGY SECTION OF THE ONTARIO MINISTRY OF THE ENVIRONMENT, WATER RESOURCES BRANCH.

THE LIMNOLOGY SECTION IS A GROUP OF ABOUT 35 SCIENTISTS AND TECHNICIANS CONDUCTING A NUMBER OF LAKE STUDIES INCLUDING SOME RELATED TO THE SUBJECT OF THESE HEARINGS - THE INFLUENCE OF SULPHUR DIOXIDE ON THE ENVIRONMENT.

MY BRIEF COMMENTS WILL GIVE YOU SOME UNDERSTANDING OF HOW OUR LAKE STUDIES GIVE DIRECT INFORMATION ABOUT THE DEGREE OF ATMOSPHERIC POLLUTION AND HOW THE SURFACE WATER QUALITY REACTS TO THAT POLLUTION.

ONTARIO OPERATES A NETWORK OF AIR QUALITY MONITORING STATIONS THAT MEASURE SULPHUR DIOXIDE IN THE AMBIENT AIR AS WELL AS THE WET DEPOSITION OF A VARIETY OF COMPOUNDS.

BULK COLLECTORS ARE OPEN AT ALL TIMES AND COLLECT PRECIPITATION PLUS SOME FRACTION OF THE PARTICULATE MATTER. THIS GIVES A PARTIAL ESTIMATE OF THE DRY DEPOSITION.

EVENT COLLECTORS OR WET - ONLY COLLECTORS ARE OPEN ONLY DURING PRECIPITATION.

THE AIR QUALITY NETWORKS HAVE A WEAKNESS IN THAT THERE IS NO INSTRUMENTATION WHICH CAN MEASURE THE DRY DEPOSITION ACCURATELY.

HOWEVER, THE LAKES, RIVERS AND WATERSHEDS THEMSELVES ARE THE ULTIMATE "COLLECTORS" OF POLLUTION DEPOSITED FROM THE ATMOSPHERE. ONE RESEARCH APPROACH THAT WE HAVE USED HAS BEEN TO CONSIDER LAKES AND WATERSHEDS AS GIANT DEPOSITION COLLECTORS. THIS CONCEPT IS CALLED "CALIBRATING WATERSHEDS AND LAKES". COMBINATIONS OF WATERSHEDS, STREAMS AND LAKES ARE SUBJECTED TO INTENSIVE MEASUREMENT. THESE CALIBRATED WATERSHEDS ARE THE PRIME SOURCE OF INFORMATION ON THE EFFECTS OF ACID RAIN. OUR MAIN STUDY LOCATIONS ARE NEAR SUDBURY AND DORSET, ONTARIO. HYDROLOGIC GAUGING STATIONS SET UP ON THE INFLOWS AND OUTFLOWS OF LAKES, ALLOW US TO MEASURE THE FLOW OF WATER AND DISSOLVED SUBSTANCES INTO AND OUT OF THE LABS AND WATERSHEDS ACCURATELY. THESE MEASUREMENTS, PERMIT THE CALCULATION OF MASS BALANCES.

COMPARISON OF THE MASS BALANCES WITH THE INPUTS MEASURED AS WET DEPOSITION CAN GIVE ESTIMATES OF DRY DEPOSITION, WHICH IS OTHERWISE VERY DIFFICULT TO MEASURE.

THE CALIBRATED WATERSHEDS ARE SUBJECTED TO DETAILED BIOLOGICAL SAMPLING AND THUS, SERVE TO QUANTIFY THE CHEMICAL AND BIOLOGICAL EFFECTS OF POLLUTANT DEPOSITION. RELATIONSHIPS ESTABLISHED BY DETAILED STUDIES CAN BE EXTRAPOLATED TO LARGE NUMBERS OF LAKES FOR WHICH LESS TOTAL DATA ARE AVAILABLE. EACH STUDY LAKE REQUIRES A GREAT DEAL OF MANPOWER AND FINANCIAL RESOURCES. THIS MEANS, THAT AT ANY GIVEN TIME THE NUMBER OF "DOCUMENTED" CASES OF EFFECTS MEASURED IN CALIBRATED WATERSHEDS IS SMALL. THE

EXTENSIVE NATURE OF THE DAMAGE MUST BE INFERRED BY EXTRAPOLATION.

FOR EXAMPLE, SOME INFORMATION WHICH IS QUITE RELEVANT TO ONTARIO'S ACTION REGARDING THE INCO SMELTER HAS COME FROM CALIBRATED WATERSHED STUDIES NEAR SUDBURY. THE TOTAL SULPHUR DEPOSITION, FOR PARTICULAR WATERSHEDS AS MEASURED BY THE MASS BALANCES IS UP TO 3.5 TIMES GREATER THAN THE FRACTION MEASURED BY BULK COLLECTION (i.e. THOSE OPEN TO THE ATMOSPHERE AT ALL TIMES, HENCE, COLLECTING RAINFALL AND SOME PARTICULATE MATERIAL, BUT NOT GASES). WHOLE LAKE CALCULATIONS HAVE SHOWN THE TOTAL DEPOSITION TO BE FROM 2.5 TO 4.2 TIMES GREATER THAN THE FRACTION MEASURED BY THE BULK COLLECTORS.¹

THESE RESULTS PROVIDE STRONG EVIDENCE OF THE INTERACTION OF ATMOSPHERIC POLLUTION AND SURFACE WATERS, AND THAT THE LARGE LOCAL SOURCE IS STILL HAVING SIGNIFICANT ENVIRONMENTAL EFFECTS.

SIMILAR STUDIES BEING CONDUCTED ON CALIBRATED WATERSHEDS IN A REMOTE AREA OF NEW YORK INDICATE THAT WHILE TOTAL DEPOSITION OF SULPHATE IS HIGH, THE APPARENT "DRY" COMPONENT, COMING FROM THE INTERACTION OF SULPHUR DIOXIDE AND SURFACE WATERS, IS LOW.²

THERE ARE A SERIES OF CALIBRATED WATERSHED STUDIES BEING CONDUCTED IN EASTERN NORTH AMERICA, EACH WITH CAPABILITIES OF MEASURING THE INFLUENCE OF WET AND DRY DEPOSITION FROM THE ATMOSPHERE.

WORK ON OUR LAKES AND STREAMS IS CONTINUING, PARTICULARLY AT DORSET, WITH WATER QUALITY CHANGES AND RESULTING BIOLOGICAL EFFECTS BECOMING BETTER DEFINED. OF COURSE, CONCLUSIONS ARE

CONSTANTLY BEING MADE FROM COMPARISONS BETWEEN OBSERVATIONS AT DORSET AND OBSERVATIONS AT OTHER LOCATIONS EXPERIENCING ACIDIFICATION OF SURFACE WATERS SUCH AS THE ADIRONDACK MOUNTAINS, SCANDINAVIA AND THE SUDBURY AREA.

AS WE HAVE INDICATED, OUR RESULTS PERTAIN TO ONTARIO, HOWEVER, SIMILAR RESULTS FROM STUDIES IN THE UNITED STATES MUST BE USED IN THE DECISION-MAKING PROCESS BY YOUR AGENCY, JUST AS THEY HAVE BEEN USED BY OUR MINISTRY.

I WILL VERY BRIEFLY TOUCH ON WHAT WE FEEL ARE SOME VERY IMPORTANT OBSERVATIONS REGARDING WATER QUALITY.

IN MOST PARTS OF THE PRECAMBRIAN SHIELD, THE ACIDS ASSOCIATED WITH THE ATMOSPHERIC DEPOSITION OF SULPHATE ARE NEUTRALIZED IN THE WATERSHED DURING MOST OF THE YEAR. RETENTION (NEUTRALIZATION) OF HYDROGEN ION DEPOSITION HAS BEEN MEASURED AT 88% AND 98% ON AN ANNUAL BASIS AT KENORA AND DORSET RESPECTIVELY.^{3,4}

HOWEVER, IN SPITE OF THE LOW TOTAL DISCHARGE OF ACID TO THE LAKES, MANY DET RIMENTAL WATER QUALITY EFFECTS ARE BEING OBSERVED. THE HYDROGEN IONS (ACID) STORED IN THE SNOW IS RELEASED IN A SHORT TIME DURING RUNOFF IN THE SPRING THAW AND MOST OF THE TOTAL ANNUAL ACID INPUT OCCURS DURING THE SPRING MELT. THE LARGE VOLUME OF WATER, COUPLED WITH LESS CHANCE FOR INTERACTION WITH THE SOIL, WHICH MAY BE FROZEN, RESULTS IN SHOCK LOADINGS OF ACID TO STREAMS AND TO THE SURFACE WATERS OF LAKES.

JEFFRIES⁵ COMPARED pH VALUES OF A SERIES OF SMALL STREAMS AND LAKE OUTFLOWS AT DORSET BEFORE AND DURING SPRING RUNOFF. (SEE TABLE 1). AT THE VERY MINIMUM, THE SURFACE WATERS OF THE ENTIRE LAKES WERE ACIDIFIED DURING THIS PERIOD OF TIME. THE LOWEST pH VALUES, 4.8 - 5.0, OBSERVED IN LAKE OUTFLOWS, ARE WITHIN A RANGE CAPABLE OF CAUSING DAMAGE TO AQUATIC LIFE, PARTICULARLY TO FISH.⁶ AS MUCH AS 75% OF THE MEASURED YEARLY ACID DISCHARGE FROM THE WATERSHEDS RAN OFF IN APRIL. FIGURE 1 SHOWS A TYPICAL HYDROGRAPH FOR ONE OF THESE STREAMS, EMPHASIZING THE HIGH SPRING WATER FLOW, HIGH ACID DISCHARGE, AND LOW pH VALUES.

THERE ARE ABOUT 30 STREAMS UNDER STUDY IN THE DORSET CALIBRATED WATERSHEDS AND SOME HAVE RESULTS FOR A PERIOD OF FIVE YEARS. THE RESULTS FOR THE HARP LAKE WATERSHED PRESENTED HERE ARE TYPICAL OF THE FULL SET OF OBSERVATIONS AND IT CAN BE CONCLUDED THAT ATMOSPHERIC ACID LOADINGS ARE CAUSING PERIODIC WATER QUALITY CHANGES. THE STUDY LAKES ALL HAVE LOW ALKALINITIES AND ARE REPRESENTATIVE OF THOUSANDS OF LAKES IN THE PRECAMBRIAN AREA.

THE DISTRIBUTION OF ALKALINITY DATA FOR A NUMBER OF LAKES THROUGHOUT THE PROVINCE IS SHOWN ON TABLE 2.

THE NUMBER OF LAKES SAMPLED IN EACH AREA TO DATE, IS SMALL IN COMPARISON TO THE TOTAL LAKES IN THESE AREAS, BUT BASED ON THIS DATA IT IS BECOMING CLEAR THAT A VERY HIGH PERCENTAGE OF THE LAKES IN THE ENTIRE PRECAMBRIAN SHIELD FALL IN THE EXTREMELY OR MODERATELY SENSITIVE CATEGORIES.

IT IS IMPORTANT TO REALIZE THAT THE ALKALINITY VALUES COVER A WIDE RANGE OF VALUES. A CERTAIN NUMBER OF LAKES WILL HAVE THE CAPACITY TO NEUTRALIZE A PARTICULAR ACID INPUT, AND THOSE WITH LESS NEUTRALIZING CAPACITY WILL BE DAMAGED. THE GREATER THE ACID INPUT, THE GREATER THE NUMBER OF LAKES AFFECTED AND THE GREATER THE DEGREE OF DAMAGE LIKELY TO BE CAUSED IN THE AFFECTED LAKES. THEREFORE, WE BELIEVE THAT ALL INCREASES IN ACID LOADINGS WILL BE DETRIMENTAL, WHILE ALL REDUCTIONS WILL BE BENEFICIAL TO SOME DEGREE.

FISH POPULATION DAMAGE IS A MAJOR CONCERN AS IT REPRESENTS LOSS TO THE SPORT FISHING INDUSTRY AND SERIOUS DISRUPTION OF THE BIOLOGICAL FOOD CHAIN SINCE MANY BIRDS AND MAMMALS DEPEND ON FISH FOR FOOD. COMPLETE LOSS OF FISH TENDS TO BE REGARDED AS THE DEFINITION OF A "DEAD" LAKE.

SOME OF THE STUDY LAKES AT DORSET HAVE BEEN SUBJECTED TO INTENSIVE FISH POPULATION MEASUREMENTS AND SEVERAL OBSERVATIONS ARE RELEVANT.

PLASTIC LAKE HAS EXPERIENCED FISH KILLS DURING SNOW MELT WHEN THE pH HAS BEEN AS LOW AS 4.7. FISH CAGING EXPERIMENTS IN THE SPRING OF 1981 HAVE CONFIRMED THE TOXIC CONDITIONS, PARTICULARLY NEAR THE INLET STREAMS, WHERE THE TEST FISH ALL DIED WITHIN TWO DAYS. THE pH AT THE INLET LOCATION WAS AS LOW AS 4.0.⁷ THERE WAS NO MORTALITY IN CONTROL STREAMS DURING THE SAME PERIOD WHERE THE pH WAS NEVER MEASURED AT LESS THAN 6.1. SIMILAR EFFECTS HAVE BEEN OBSERVED IN LAKES IN NORWAY AND SWEDEN.^{8,9}

WHITE SUCKERS ARE AN IMPORTANT "TEST SPECIES" SINCE THEY ARE NOT SUBJECT TO MUCH DIRECT FISHING PRESSURE AND THEREFORE, CHANGES IN POPULATION ARE MAINLY DUE TO ENVIRONMENTAL EFFECTS.

IN ONE STUDY LAKE, A DISTINCT SHIFT TOWARD A YOUNGER AVERAGE AGE OF WHITE SUCKERS WAS OBSERVED. THIS IS BELIEVED TO BE A CHARACTERISTIC RESPONSE TO LAKE ACIDIFICATION. SIMILAR EFFECTS HAVE BEEN OBSERVED IN NORWAY.¹⁰

YET ANOTHER STUDY LAKE HAS A YEAR CLASS OF THIS SPECIES MISSING. THIS IS ALSO A CHARACTERISTIC OF LAKES SUBJECT TO ACIDIFICATION DAMAGE.

THESE OBSERVATIONS PROVIDE STRONG EVIDENCE THAT THE FISHERIES ARE BEGINNING TO SUFFER UNDER THE PRESENT ACID LOADING CONDITIONS. IT IS REASONABLE TO ASSUME THAT SIMILAR CHANGES ARE TAKING PLACE IN THE MANY THOUSANDS OF LAKES WITH SIMILAR ALKALINITIES WHICH ARE LIKELY EXPERIENCING SIMILAR WATER QUALITY EFFECTS.

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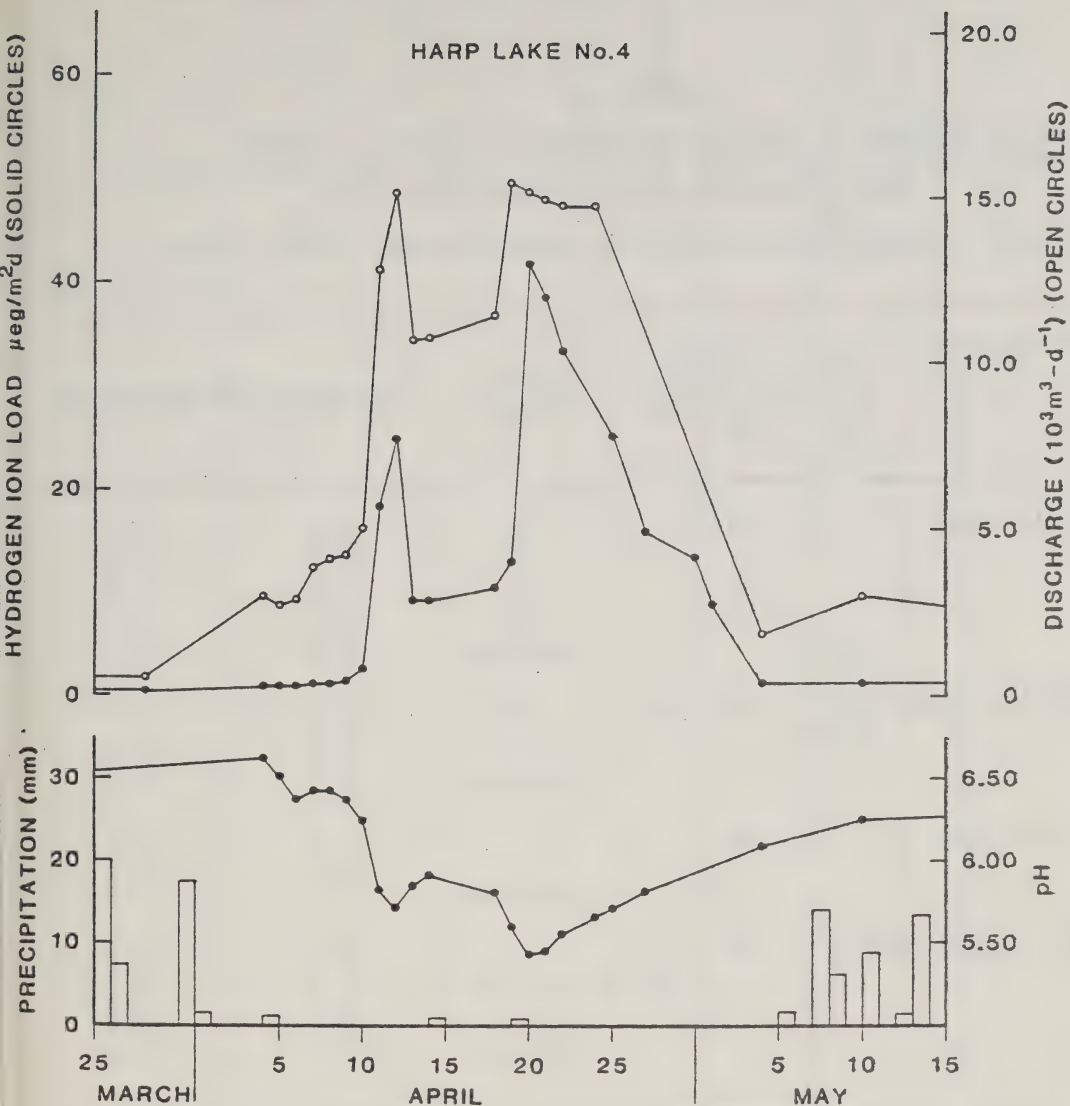


Figure 1: "Spring pH Depression" of a Stream

Graph illustrating "spring pH depression" in one of the six inflowing streams to Harp Lake, a study lake in Muskoka.

As the spring runoff increases the amount of water, the acidic melted snow causes the stream pH to drop, producing severe chemical "shock" effects on aquatic life.

TABLE 1

pH OF STREAMS IN MUSKOKA-HALIBURTON, ONTARIO, CANADA:
STREAM pH IS GIVEN PRIOR TO SPRING RUNOFF (MID-MARCH 1978)
AND AT MAXIMUM RUNOFF (MID-APRIL 1978)

Annual Average Alkalinity data from Scheider (Pers. Comm)

Watershed	Annual Average Alkalinity µeq/l	Stream Number	pH	
			Mid-March	Mid-April
Harp Lake	96	3	6.1	5.1
		3A	6.0	5.6
		5	5.9	4.8
		6	6.2	5.3
		6A	5.4	5.0
		Outflow	6.3	5.0
Dickie Lake	55	5	4.6	4.3
		6	4.6	4.4
		11	4.9	4.1
		Outflow	5.6	4.9
Chub Lake	61	1	5.8	5.1
		2	5.2	4.7
		Outflow	5.5	4.8
Red Chalk Lake	92	1	6.1	5.6
		2	4.5	4.3
		3	6.0	5.5
		4	6.2	5.5
		Outflow	6.1	5.9

Partial Table From: Jeffries et al., 1979

TABLE 2 SUMMARY OF THE PERCENTAGE OF LAKES IN EACH ALKALINITY CLASS BY COUNTY OR DISTRICT

Percentage of Total No. of Lakes in each Alkalinity Class						Total No. of Lakes Surveyed In County District
County or District	Acidified (< 0 $\mu\text{eq/l}$)	Extreme Sensitivity (> 0 to 39.9 $\mu\text{eq/l}$)	Moderate Sensitivity (40 to 199 $\mu\text{eq/l}$)	Low Sensitivity (200 to 499 $\mu\text{eq/l}$)	Not Sensitive (> 500 $\mu\text{eq/l}$)	
Algoma District	5	11	30	28	26	163
Bruce Co.					100	7
Cochrane Dist.		7		11	82	27
Durham Co.					100	1
Frontenac Co.				6	94	64
Grey Co.		24		22	100	3
Haliburton Co.			39	11	15	112
Hastings Co.			21		68	63
Huron Co.					100	1
Kenora Dist.			14	25	61	88
Lanark Co.					100	15
Leeds Co.					100	24
Lennox & Addington Co.			36	12	52	25
Manitoulin Dist.	52	29	3	3	13	31
Middlesex Co.					100	1
Muskoka Dist.	1	30	61	2	6	115

...continued/

Percentage of Total No. of Lakes in each Alkalinity Class

County or District	Acidified (< 0 $\mu\text{eq/l}$)	Extreme Sensitivity (> 0 to 39.9 $\mu\text{eq/l}$)	Moderate Sensitivity (40 to 199 $\mu\text{eq/l}$)	Low Sensitivity (200 to 499 $\mu\text{eq/l}$)	Not Sensitive (≥ 500 $\mu\text{eq/l}$)	Total No. of Lakes Surveyed In County/ District
Nipissing Dist.		9	75	13	3	75
Northumberland Co.					100	1
Ontario Co.					100	5
Parry Sound Dist.	5	20	64	10	1	107
Peel Co.					100	1
Peterborough Co.		4	16	6	74	49
Prince Edward Co.					100	3
Rainy River Dist.		3	64	19	14	99
Renfrew Co.			8	32	60	50
Simcoe Co.					100	7
Storont Co.					100	1
Sudbury Dist.	24	29	23	12	12	210
Thunder Bay Dist.	1	.2	25	27	45	136
Timiskaming Dist.	13		7	27	53	30
Victoria Co.					100	11
York Co.					100	2
						1,527

WHAT MODELLING TELLS US ABOUT ONTARIO, NEW YORK AND PENN-
SYLVANIA TRANSBOUNDARY AIR POLLUTION

1. INTRODUCTION:

Until a few years ago, we were primarily concerned with air quality in the vicinity of a pollutant source. Concentrations were considered high, if they were above levels determined to be harmful to plants and human health. Using this criterion, even large pollutant sources could be considered to have little effect beyond distances of the order of tens of kilometers from the source. This way of looking at pollution ignored the effects of the large fraction of the emission which left this region of "local" air quality effects.

It is to be noted that applying the conventional short range models recommended by EPA, all the pollutants escape to greater distances, although in small concentrations. If we apply dry and wet deposition to the plume, then approximately 80 - 90% of the pollutants would escape to greater distances depending on stack height. This is assuming that 10% of the time the plume encounters precipitation at the release point.

It is only recently that we have become aware of the cumulative effect of small concentrations from a large number of sources. Secondary pollutants from several sources can be high at distances of hundreds of kilometers from the source region. Furthermore, the occurrence of acid rain has forced us to redefine the meaning of "high" as applied to local air quality.

Analysis of meteorology during high TSP episodes has shown the role of long-range transport. Mathematical modelling has also indicated the extent of pollution caused by long range transport. These models also determine the source-receptor relationships and develop emission control strategies.

2. MODELLING ISSUES

a. What is a LRT model?

A LRT model is a description of the relevant physical system in the precise language of mathematics. Physical relationships in the system are replaced by logical mathematical connections or equations. Cause-effect relationships can be investigated by routine manipulation of equations. Since the physical system is extremely complex, this description or model is necessarily incomplete. Models attempt to include variables which control the physical system.

b. What does a model predict?

In theory, a perfect model is possible. In practice, this is impossible because even if we had all the equations to describe the system, we would not have the information to run the model. Specifically, we could predict the fate of released particles if we had the velocity field completely specified at all points in space and time. This is clearly impossible. Consider the fact that wind monitors are spaced at typical distances of tens of kilometers. This means that we do not know the velocity field between the monitors. This lack of information prevents us from predicting the concentration field corresponding to the precise time interval the velocities are measured. Then what does a model predict?

Models are designed to predict the average over the concentrations corresponding to the model inputs. In a long-range transport model these inputs typically consist of velocities, mean and their statistics, precipitation and mixed layer height. Since these inputs do not constitute all the information needed to estimate the observed concentration, we expect the model prediction to deviate from an observation.

c. How do you use model results?

Model predictions are expected to deviate from corresponding observations. The expected deviation is a function of averaging time. It decreases as the averaging time increases. In other words, the deposition at a receptor averaged over five years will deviate less from the model prediction than one year average will. What does the model tell us if the emission from a source is reduced? A reduction in emission increases the probability that the deposition will be below a given target value. The model cannot tell you whether the actual deposition with the new emission rate will be below that corresponding to the old emission rate. Decisions have to be based on probability rather than certainty. As an example, consider the automobile speed limit. We reduce the speed so that the probability that accidents occur decreases. Clearly,

we do not expect this decrease in speed limit to result in a decrease in the accident rate on the first day after the new speed limit is posted. On the other hand, it is reasonable to expect a decrease over a period of months.

d. Long-range transport modelling:

The effect of a single large source is "small" at large distances from the source. However, the cumulative effect of a large number of sources can be large. This is the crux of the long-range transport problem. This means that the small contribution from a source area is important relative to other small contributions. To be specific, consider 20 sources, each of which contributes 5% to the deposition at a sensitive area. If the total deposition is $2 \text{ g m}^{-2} \text{ yr}^{-1}$, each source contributes only $0.1 \text{ g m}^{-2} \text{ yr}^{-1}$. Under these circumstances, we have to assume that all the sources are equally guilty of causing the problem. A doubling of any one source doubles the culpability of the source relative to the other sources. The deposition at the receptor would become $4 \text{ g m}^{-2} \text{ yr}^{-1}$ if all the sources decided to double their emissions.

3. MOE MODEL

Let me describe to you the model used in our submission and

some typical outputs of this model. The model (Venkatram et al 1981) is statistical in nature and simple. The only inputs required by the model are emission fields and receptor points.

The model has three components, transport and dispersion, wet and dry scavenging, and chemistry. Transport and dispersion, is treated in a simple manner by prescribing the distribution of pollutants, inside a long-range, long-term plume with respect to a source. Linear chemistry is incorporated, due mainly to the lack of sufficient knowledge on non-linear chemistry. Wet and dry scavenging is treated in a unique manner by assuming a puff, released from the source, to encounter wet period and dry periods in a statistical sense. The model uses a background of $0.2 \text{ g/m}^2/\text{yr}$ of wet deposition of sulphur. The background is attributed to biogenic sources and sources not accounted for in the model.

The model has been extensively reviewed by peers in the field and has been accepted for publication in an international journal, Atmospheric Environment. This attests to the merits of the model.

4. Results

1. The first transparency shows the distribution sources in the inventory used in the model. The inventory is based on EPA's point source inventory compiled by Benkowski of BNL from the NEDS and point and area source inventory of GCA. The Canadian sources are obtained from the AES, Canada and MOE inventories.

All large (≥ 100 K Tonnes/yr) point sources and 95% of major (≥ 10 k Tonnes/yr) point sources were incorporated into the model's inventory to form effective point sources located at the emission-weight geometric means of the co-ordinates of the contributing points. Care was taken to amalgamate only sources situated in similar geographic settings and, in general, less than 50 Km apart. Approximately 60% of all area sources and 72% all minor point sources were incorporated into the inventory adding minor point sources and area sources located near (≤ 50 km) major points to that point or combining small sources concentration in large urban centers to form effective point sources.

2. The 2nd transparency shows the isopleths of total wet deposition of Sulphur as predicted by the model. Note that they are all long term averages. The circles denote monitor locations; the large numerals being monitor codes.

3. The 3rd transparency shows the validation of model predictions of total wet sulphur deposition with observed data.

A background value of $.2\text{g/m}^2/\text{yr}$ has been added to the model predictions to account for sources which have not been considered in the inventory and biogenic sources such as sea spray, volcanoes etc. The geometric mean and standard deviation of the observed minus predicted is 1.16 and 1.64 attesting to the validity of the model. The "ideal" value of m_3 is unity.

4. The 4th transparency shows isopleths of $\text{SO}_4^=$ air concentrations predicted by the model.

5. The 5th transparency shows validation of the model predictions for $\text{SO}_4^=$ concentration. A back ground value has not been added here as we don't yet know what this background value is. Nevertheless the comparison between the model predictions and observed data is quite good. If we add a background value of $1.9\text{ }\mu\text{g/m}^3$ the geometric mean and standard deviation becomes .99 and 1.4.

6. The 6th transparency shows the isopleths of SO_2 air concentration predicted by the model. In view of the fact that monitors for ambient SO_2 concentration are not strictly free of local source effects we have not validated the model as yet for SO_2 . The levels of SO_2 concentrations are reasonable.

7. The 7th transparency shows the relative contribution of SO_2 to total wet sulphur deposition. This large contribution is attributed to rapid incloud oxidation of SO_2 to $\text{SO}_4^=$. This insitu formation of $\text{SO}_4^=$ leads to efficient washout of SO_2 . It is noted that SO_2 is efficiently dry deposited too. $\text{SO}_4^=$ however, is not dry deposited efficiently.

8. The 8th transparency shows a list of 20 power plants cited in the NY submission.

9. The 9th transparency shows the results of the contribution of these 20 power plants. The first column shows the magnitudes of total wet deposition of sulphur to the 6 sensitive receptors. The other 4 columns show the percentage contributions from 1979 emission levels of the 20 sources, the decrease in percent if 1979 actual emissions were reduced to 1979 SIP maximums, percent increase if emissions rise from 1979 SIP max. to proposed maximum respectively.

10. The 10th transparency shows the results of the contribution of these 20 power plants to the SO_4 air concentration.

The 1st column shows the magnitudes of long term average SO_4 concentration to the 6 sensitive receptors. Columns 2-5 show the percentage contributions from 1979 emission levels of the 20 sources, the decrease in percent if 1979 actual emissions were reduced to 1979 SIP maximums, percent increase if emissions rise from actual 1979 levels to proposed new limits, and percent increase if emissions rise from 1979 SIP maximums to proposed maximums respectively.

11. The 11th transparency shows the results of the contribution of these 20 power plants on air concentration of SO_2 .

The 1st column shows the magnitudes of long-term average SO_2 concentration to the 6 sensitive receptors. Columns 2-5 show the percentage contributions from 1979 emission level of the 20 NY sources, the decrease in percent if 1979 actual emissions were reduced to 1979 SIP maximums, percent increase if emissions rise from actual 1979 levels to proposed new limits, and percent increase if emissions rise from 1979 SIP maximums to proposed maximums respectively.

12. The 12th transparency shows the 53 sources cited by Pennsylvania and N.Y. in the Federal Register.

13. The 13th transparency shows the magnitude of total annual wet deposition of sulphur at the 6 sensitive receptors and the percent contribution by the 53 sources cited by Penn. and N.Y.. Also shown is a breakdown of contributions from other sources.

I wish to note that the emissions from INCO used in these calculations were 1600 short tons/day. Previous speaker have intimated that the tonage from INCO is 3600 short tons/day and this is a distortion of the actual situation. In actual fact the current regulated maximum emission level of INCO is 2500 short tons/day and because of strikes and shut-downs during the 1978 and 1979 period the average daily level for these years was less than 1600 short tons/day.

The confusion about emission inventories does not help any of us discuss the issues of transboundary pollution in a clear manner.

14 The 14th transparency presents the magnitude of the long-term average SO_4 concentration at the six receptors and the percent contribution by the 53 sources. The contribution from other sources is also shown.

15. The 15th transparency presents the magnitude of the long-term average SO_2 concentration at the six sensitive receptors and the percent contribution by the 53 sources. Also the contribution from other sources is shown.

5. SUMMARY OF RESULTS

These results have shown the percentage contributions to the sensitive receptors for various source configurations. In view of the fact that the model predicts an average value we should not expect that a single year's observation would agree with this prediction.

The issue before us is the magnitude of increase in pollutant concentration due to an increase in emission levels. There is no simple answer to this problem. The problem can be traced to the extremely complex nature of turbulent flows which have not been amenable to a simple solution. The importance of this question has currently been brought to the forefront and several workshops (Woodshole Workshop, Work Group II workshops) have been held on this subject. It is the consensus of the scientists globally that more work is needed to resolve this problem. For the moment the verification techniques are being standardised and the criteria of validation of models are being formulated.

6. DECISION MAKING

I would like to bring to the notice of the panel some other areas where decisions are made regularly in spite of the uncertainties in the data. For example, no one can predict precisely the formation of tornadoes in space and time. Yet, living quarters are built regularly. Dams are constructed from a subset of data on water flows in rivers. Crops are planted in spite of the uncertainties in weather. Economic decisions are made daily on econometrics models in spite of their uncertainties.

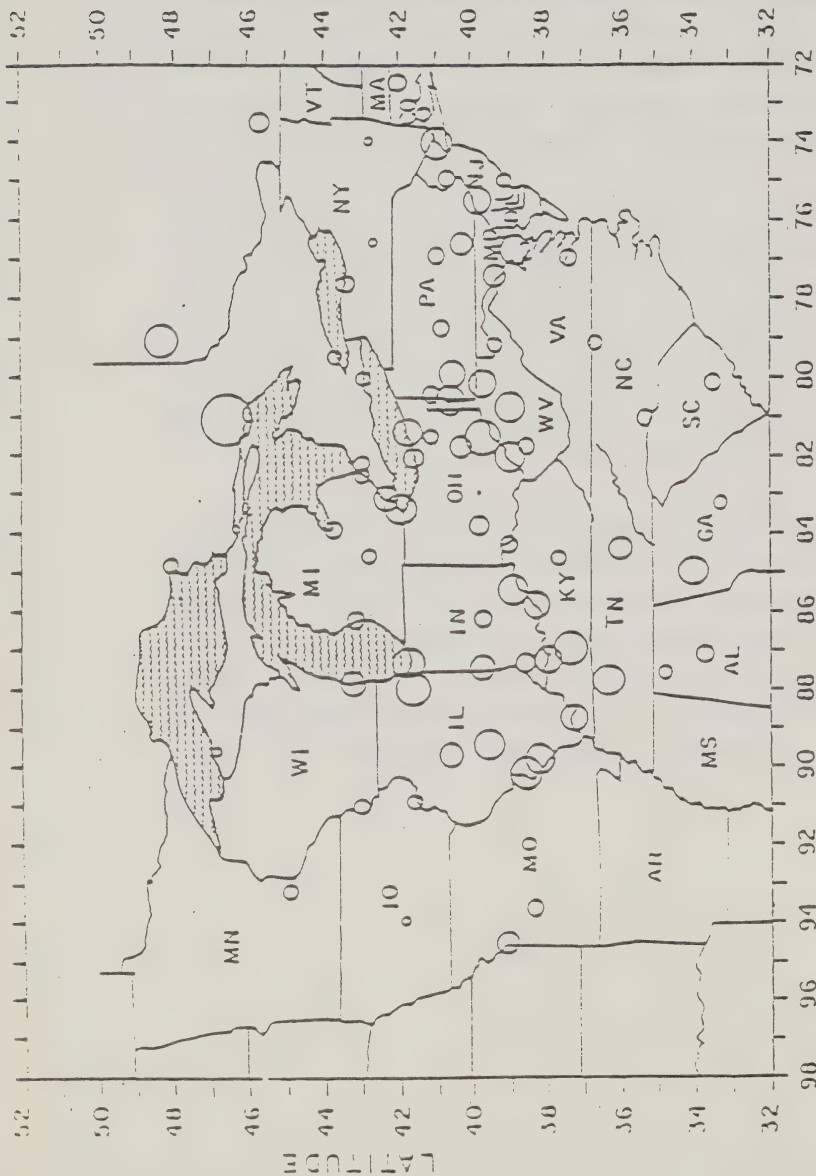
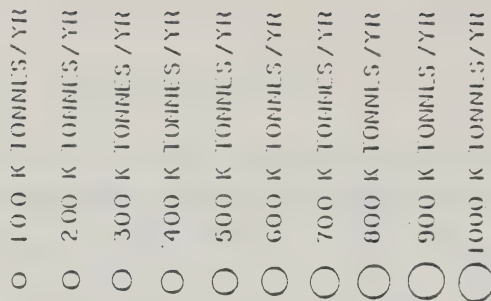
We recognize that increase in sulphur deposition is going to damage the ecosystem in the sensitive areas. We also recognize that there are uncertainties in models and that expectations that perfect models would be available in the near future are unrealistic. Let me ask you, can we afford not to react now with the available information however uncertain it may be?

Precedents exist in the abatement area where decisions have been made on model results. For example, use of Freon in spray cans has been banned on model results that Freon released from these cans would upset the O_3 layer. Therefore, we should not be afraid to act now and base decisions on models even if air quality models today lack the precision that we would all like them to have.

Conclusions:

In my presentation today I have described the model in relation to the terms of reference of the hearing. We have used the model for Ontario for emission control. Mr. Scott, the next speaker, will discuss the way in which these results have been used.

LEGEND



LONGITUDE

SOURCES OFF THE MAP

EMISS	SOURCE NAME	LAT	LONG	EMISS	SOURCE NAME	LAT	LONG
○	PORTLAND - AUGUSTA	43.4	71.0	○	FLIN FLON MAN	54.9	101.0
○	BOSTON - WORCESTER	40.3	71.3	○	MONCTON N.D.	45.5	66.0
○	NEWPORT - FALL RIVER	41.7	71.1	○	NOVA SCOTIA	45.0	62.8
○	THOMPSON, MAN	55.4	97.5	○	GASPE BAY QUEBEC	40.6	65.3

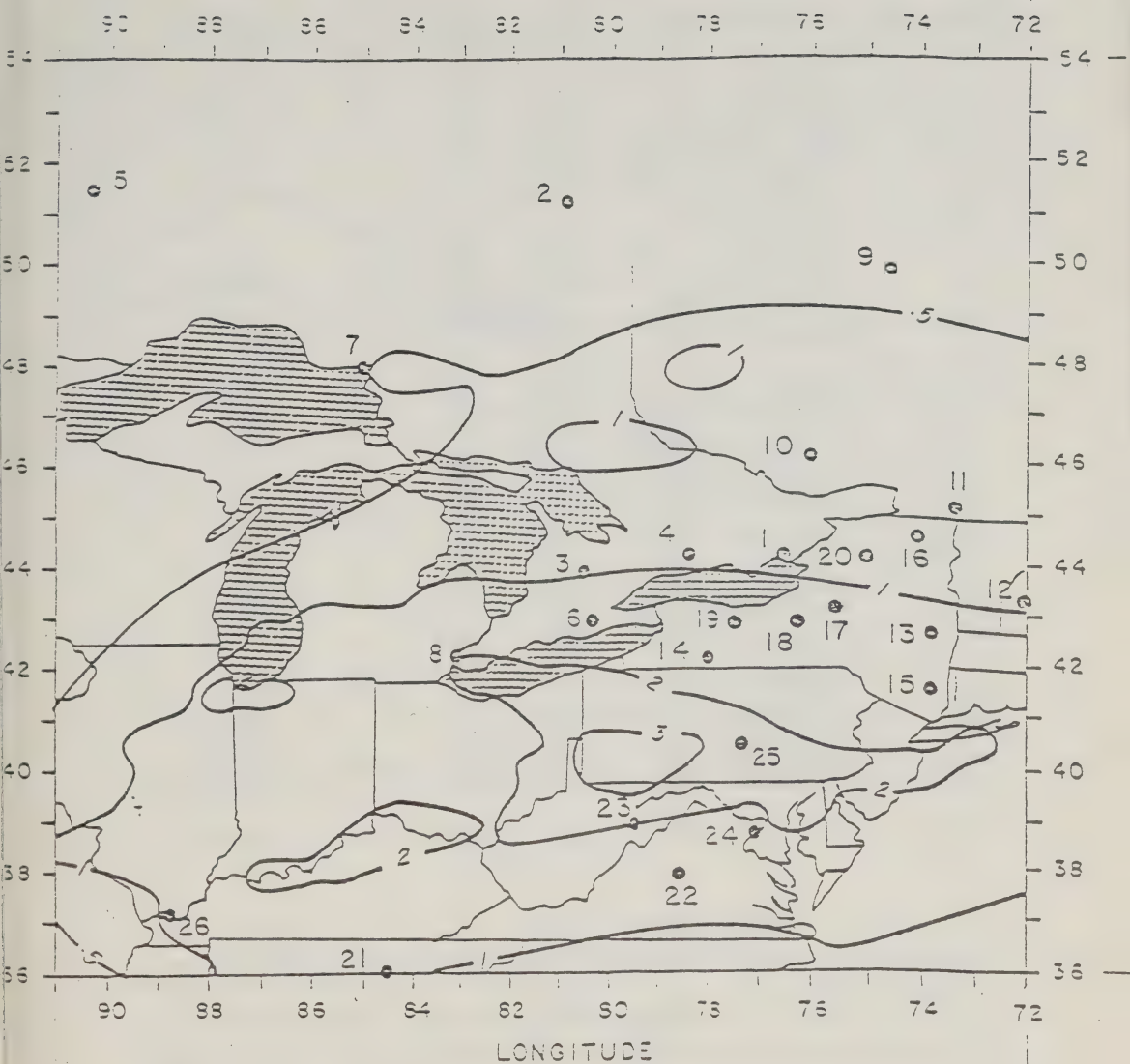


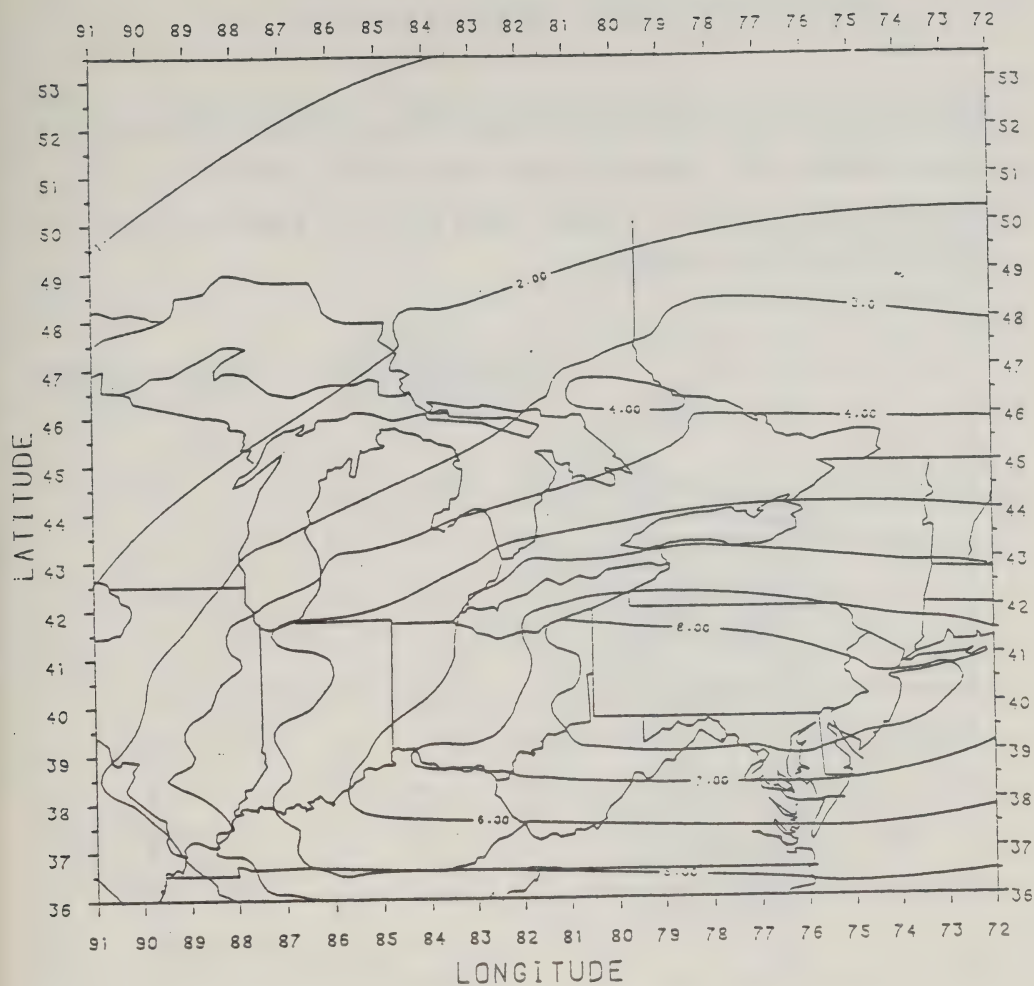
FIGURE 3: Model predictions of annual wet deposition of sulfur in $\text{g/m}^2/\text{a}$. Stars in figure correspond to monitors in the CANSAF and U.S. networks. Numbers next to stars are station codes referred to in Table 2.

Total Annual Wet Deposition of
Sulphur Comparison of Observed
OME Model Estimate

<u>Station No.</u>	<u>Receptor Name</u>	<u>OBS</u> ($\text{gm}^{-2}\text{a}^{-1}$)	<u>PRED</u>	<u>OBS/PRED</u>
1	Kingston, Ont.	1.26	0.93	1.35
2	Moosonee, Ont.	0.58	0.33	1.76
3	Mount Forest, Ont.	2.32	0.96	2.42
4	Peterborough, Ont.	1.81	0.94	1.93
5	Pickel Lake, Ont.	0.39	0.28	1.39
6	Simcoe, Ont.	2.34	1.49	1.57
7	Wawa, Ont.	0.91	0.52	1.75
8	Windsor, Ont.	2.98	2.00	1.49
9	Chibougamau, Que.	1.06	0.42	2.52
10	Maniwaki, Que.	0.71	0.75	0.95
11	Montreal, Que.	2.35	0.88	2.67
12	Merrimach Cnty, N.Y.	0.91	0.93	0.98
13	Albany Cnty, N.Y.	1.20	1.21	0.99
14	Allegany Cnty, N.Y.	2.20	1.58	1.39
15	Dutchess Cnty, N.Y.	1.20	1.48	0.81
16	Essex Cnty, N.Y.	0.84	0.84	1.00
17	Oneida Cnty, N.Y.	1.70	1.08	1.57
18	Onondaga Cnty, N.Y.	0.79	1.19	0.66
19	Ontario Cnty, N.Y.	1.20	1.34	0.90
20	St. Law. Cnty, N.Y.	1.00	0.89	1.12
21	Oak Ridge, Tenn.	1.30	1.04	1.25
22	Charlottesville, Vir.	0.91	1.31	0.69
23	Tucker Cnty, W.V.	2.00	1.94	1.03
24	Washington, D.C.	1.00	1.83	0.55
25	Lewistown, Penn.	0.98	2.21	0.44
26	Paducah, Kentucky	0.57	1.29	0.44

LINEAR ANALYSIS: OBSERVED DEPOSITION = a + b * PREDICTED DEPOSITION

<u>Receptor Location</u>	<u>r²</u>	<u>a(g/m²/yr)</u>	<u>b</u>	<u>Receptor Excluded</u>
Canada	0.76	0.24	1.49	
Canada	0.84	0.16	1.48	11
U.S.	0.89	0.73	0.34	
U.S.	0.47	0.05	0.88	24, 25, 26
All PT	0.19	0.67	0.88	
All PT	0.51	0.24	1.04	11, 24, 25, 26
All PT Can Obs Reduced 80%	0.75	0.12	0.87	11, 24, 25, 26



Long term average SO_4^{2-} concentration (assuming no background) contoured in $1\mu\text{g}/\text{m}^3$ intervals. Calculated using the QAE long-range statistical model.

Long-term Average SO_4 Concentrations

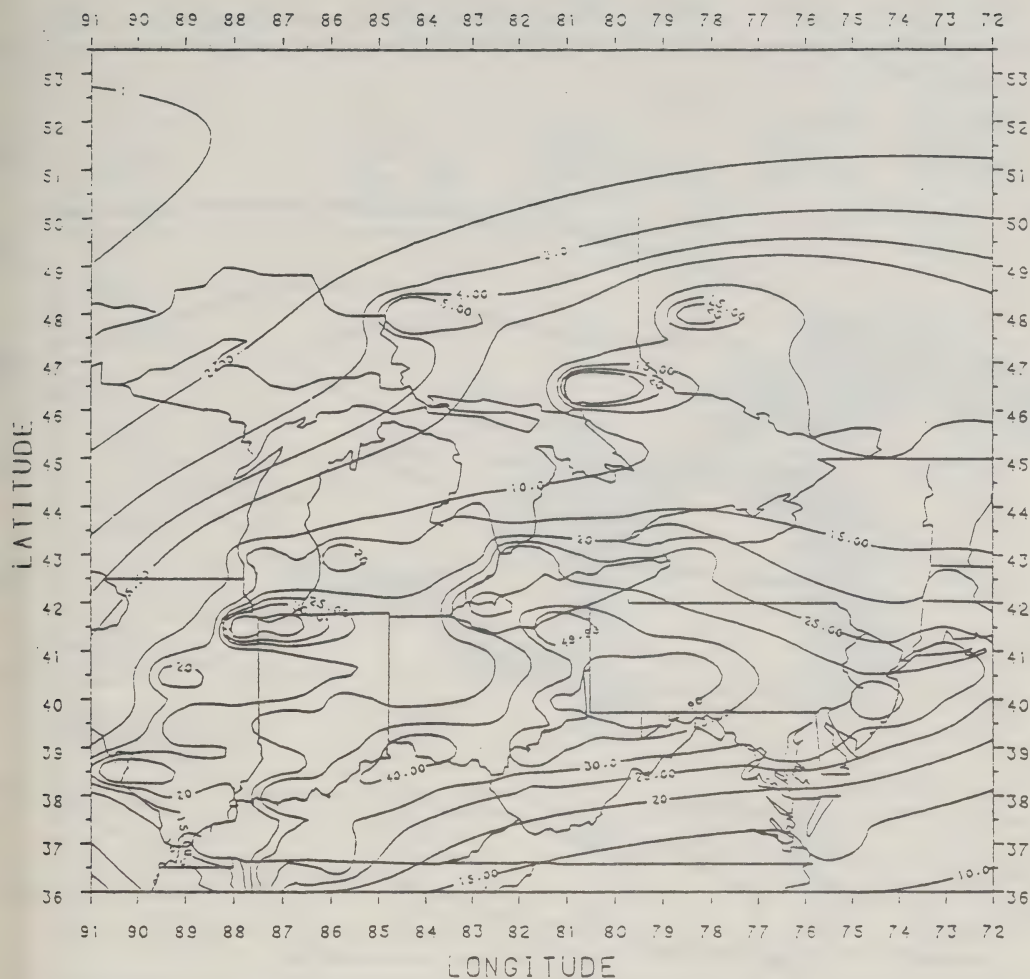
Intercomparison of MOE statistical Model, estimate of
 SO_4
 Annual average SO_4 concentrations with annual average
 concentrations at the 9 Class I SURE Phase II stations for
 different averaging times:

Station	Avg. Observed Concentrations* (microgram/m ³)			Model Estimate (microgram/m ³)
	(1)	(2)	(3)	
1. Montague, Amherst MA (72.6, 42.38)	3.3	5.6	5.2	6.4
2. Scranton, Scranton PA (75.70, 41.40)	7.9	7.8	7.4	7.6
3. Indian R., Millsboro DE (75.30, 38.58)	7.0	6.9	6.7	7.2
4. Philo, Janesville OH (82.0, 39.92)	9.2	8.3	7.5	7.6
5. Rockport, Owensboro KY (87.1, 37.75)	9.5	8.2	7.8	5.0
6. Giles City, Huntsville AL (86.6, 34.7)	8.9	8.4	8.2	2.5
7. Ft. Wayne, Ft. Wayne IN (85.2, 41.08)	8.2	7.8	7.5	5.4
8. Chapel Hill, Raleigh NC (78.7, 35.75)	7.6	7.6	7.5	4.4
9. Lewisburg, Lewisburgh WV (80.45, 37.8)	7.7	8.0	7.7	6.3

Averaging time:

- (1) August 1977 - July 1978
- (2) November 1977 - October 1978
- (3) August 1977 - June 1978

* B.L. Niemann (1980)



Long term average SO_2 concentration (assuming no background) contoured in $5\mu\text{g}/\text{m}^3$ intervals. Calculated using the OME long-range statistical model.

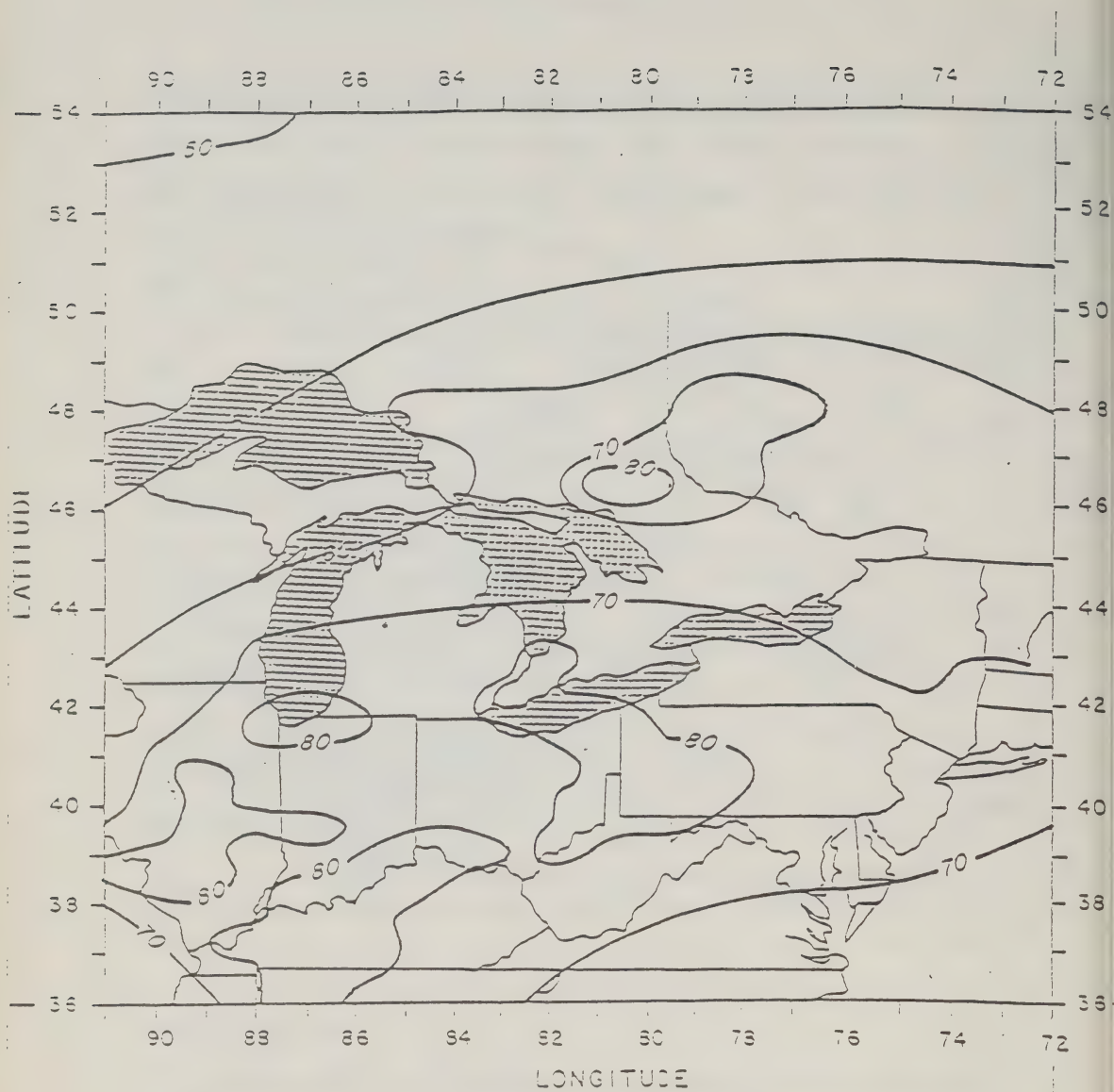


FIGURE 4: Relative contribution of SO_2 to the total wet deposition of sulfur.

TABLE 2: U. S. Coal-Burning Power Plants Proposing an Increase in their SO₂ Emission Limits

NOTE: All figures are in thousands of metric tons.

<u>STATE</u> Power Plant	Amount Allowable Under 1979 Regulation	Proposed Increase in Emissions Above Regulation	Proposed Total Emission	Estimated 1979 SO ₂ Emissions
<u>ILLINOIS</u>				
1) Baldwin	228.7	54.4	283.1	257.9
<u>INDIANA</u>				
2) Clifty Creek	46.2	174.5	220.7	263.7
3) Tanners Creek	26.1	116.6	142.7	85.2
4) Michigan City	17.0	84.1	101.1	62.4
5) Culley	12.5	50.4	62.9	61.5
6) Bailly	13.9	46.6	60.5	38.0
7) Stout, Elmer W.	17.6	72.2	89.8	44.2
8) Warrick	4.3	111.7	116.0	20.2
9) Mitchell, Dean H.	13.6	62.2	75.8	19.2
<u>MICHIGAN</u>				
10) Cobb	40.3	20.2	60.5	69.3
11) Campbell	39.2	19.5	58.7	57.0
<u>OHIO (I)</u>				
12) Muskingum	235.0	150.5	385.5	340.2
13) Cardinal	214.1	68.6	282.7	140.8
14) Beckjord	136.0	9.2	145.2	99.7
15) Poston	16.3	16.3	32.6	29.1
16) Bayshore	19.3	16.2	35.5	23.7
<u>TENNESSEE</u>				
17) Kingston	51.0	90.2	141.2	87.2
<u>WEST VIRGINIA</u>				
18) Kammer	63.6	157.3	220.8	136.8
<u>OHIO (II)</u>				
19) Avon Lake	26.0	111.4	137.4	98.0
20) East Lake	36.5	131.4	167.9	137.4
<u>TOTAL</u>	<u>1257.2</u>	<u>1563.5</u>	<u>2820.7</u>	<u>2091.3</u>

Contributions of wet sulphur deposition from 20 U.S. power plants including Avon Lake and Eastlake under various emissions cases to environmentally sensitive areas in Canada and the U.S.

Note: Each column presents data connected with the plants' emissions, as described. Where noted, the data are expressed as wet deposition percentages, with the normalizing factor being the total wet deposition occurring in 1979 due to actual emissions from all sources. This is the data listed in the first column.

Note: Model predictions have been verified to be accurate within a factor of 2 with 60% of estimates within 35% of expected values.

Sensitive Region	Total Wet Sulphur Deposition g/m ² /yr.	Per Cent Amount due to actual 1979 emissions	Per Cent Decrease occurring if 1979 actual emissions were reduced to 1979 SIP maximums.	Per Cent Increase occurring if emissions rise from actual 1979 levels to proposed new limits	Per Cent Amount due to emissions if they are held at 1979 SIP limits (Column 1 minus 2)	Per Cent Amount due to emissions if they rise to proposed new limits (Column 1 plus 4)

Muskoka-Haliburton, Ontario	0.67	4.5	2.0	1.4	3.4	5.9
Algoma, Ontario	0.47	3.0	1.3	0.9	2.2	3.9
Lakehead, Ontario	0.28	1.9	0.8	0.7	1.4	2.6
Val D'Or, Quebec	0.61	2.7	1.1	0.8	2.0	3.5
Adirondacks, N.Y.	0.83	5.5	2.3	1.9	4.3	7.4

20 U.S. Power Plants listed by New York to
Environmentally Sensitive Areas in Canada and
the U.S.

Note: Each column presents data connected with the plants' emissions, as described. Where noted, the data are expressed as SO₂ concentration percentages, with the normalizing factor being the total SO₂ concentration occurring in 1979 due to actual emissions from all sources. This is the data listed in the first column.

Sensitive Region	Long-term Average SO ₂ Concentration, (micrograms/m ³) emissions	Per Cent Amount due to actual 1979 emissions	Per Cent Decrease occurring if 1979 actual emissions were re- duced to 1979 SIP maximums.	Per Cent Increase if emissions rise from actual 1979 levels to proposed new limits.	Per Cent Increase occurring if emissions rise from 1979 SIP max to proposed max.	Per Cent Amount due to emissions if they are held at 1979 SIP limits (Column 1 minus 2)	Per Cent Amount due to emissions if they rise to proposed new limits (Column 1 plus 4)
Albion, Ontario	3.43	7.5	3.2	2.5	5.7	4.3	10.0
Algonia, Ontario	2.13	6.9	2.9	2.2	5.1	4.0	9.1
Alkhead, Ontario	0.98	7.2	3.0	2.4	5.4	4.2	9.6
Albion, Quebec	2.76	6.2	2.6	2.1	4.7	3.6	8.3
Adirondacks, N.Y.	4.59	7.9	3.3	2.7	6.0	4.6	10.6
Adirondack West	7.65	11.1	4.0	4.3	8.3	7.1	15.4

Contribution to SO₂ Concentration from
20 U.S. Power Plants listed by New York
to Environmentally Sensitive Areas in
Canada and the U.S.

Note: Each column represents data connected with the plants' emissions, as described. Where noted, the data are expressed as SO₂ concentration percentages, with the normalizing factor being the total occurring in 1979 due to actual emissions from all sources. This is the data listed in the first column.

Region	Long-term Average SO ₂ Concentration (micrograms/m ³)	Per Cent Amount due to actual 1979 emissions	Per Cent Decrease occurring if 1979 actual emissions were re- duced to 1979 SIP maximums.	Per Cent Increase occurring if emissions rise from actual 1979 levels to proposed new limits	Per Cent Increase occurring if emissions rise from 1979 SIP max to proposed max.	Per Cent Amount due to emissions if they are held at 1979 SIP limits (Column 1 minus 2)	Per Cent Amount due to emissions if they rise to proposed new limits (Column plus 4)

Saskatoon,
Saskatchewan

7.86

5.9

2.6

1.8

4.4

3.3

7.7

Sturgeon,
Ontario

4.40

4.3

1.9

1.3

3.2

2.4

5.6

Lakehead,
Ontario

0.96

6.0

2.5

2.0

4.5

3.5

8.0

Val d'Or,
Quebec

6.98

3.1

1.3

1.0

2.3

1.8

4.1

Adirondacks,
N.Y.

10.64

6.9

2.9

2.5

5.4

4.0

4.0

TABLE 1

Sources listed by the "Federal Register"* and "Inside EPA"*
 cited by Pennsylvania and New York for the
 Proceedings under Section 126

			Emission (10^3 tonnes SO_2 /yr)
N	KINCAID	ILLINOIS	136.3
P	CAVIN	OHIO	339.5
P	KYGER CREEK	OHIO	205.5
P	CONSVILLE	OHIO	186.8
P	SAMMIS	OHIO	160.7
P	BURGER	OHIO	79.0
P	NILES	OHIO	30.9
P	TORONTO	OHIO	29.6
P	MITCHELL	W. VIRGINIA	186.2
P	HARRISON	W. VIRGINIA	142.8
N	BALOWIN	ILLINOIS	257.9
N	CLIFTY CREEK	INDIANA	263.7
N	TANNERS CREEK	INDIANA	85.2
N	MICHIGAN CITY	INDIANA	62.4
N	CULLEY	INDIANA	61.3
N	BAILLY	INDIANA	58.0
N	STOUT, ELMER W,	INDIANA	44.2
N	WARRICK	INDIANA	20.2
N	MITCHELL, DEANH	INDIANA	19.2
N	COBB	MICHIGAN	69.3
N	CAMPBELL	MICHIGAN	57.0
NP	MUSKINGUM	OHIO	340.2
NP	CARDINAL	OHIO	140.8
N	BECKJORD	OHIO	99.7
N	POSTON	OHIO	29.1
N	BAYSHORE	OHIO	23.7
N	KINGSTON	TENNESSEE	87.2
NP	KAMMER	W. VIRGINIA	136.8

P	FED PAPER	OHIO	1.9
P	TORONTO PAPER	OHIO	50.9
P	NSC WEIRTON	OHIO	0.2
P	NORTH	OHIO	4.8
P	SOUTH	OHIO	3.7
P	YORKVILLE	OHIO	3.1
P	MARTIN'S FERRY	OHIO	1.1
P	ALLIED CHEMICAL	W. VIRGINIA	1.1
P	BANNER FIREBORD	W. VIRGINIA	0.4
P	NSC WEIRTON	W. VIRGINIA	80.9
P	GLOBE REFRACT	W. VIRGINIA	3.0
P	KOPPER	W. VIRGINIA	4.4
P	MOBAY	W. VIRGINIA	2.7
P	DENWOOD	W. VIRGINIA	3.7
P	AREA SOURCE ⁺	W. VIRGINIA	1.0
P	OHIO VALLE MC	W. VIRGINIA	0.1

+ Area source includes 10 small sources all in the Moundsville-Weirton area all with total annual SO₂ emissions of less than .1 ktonne.

* Vol 46, No 84, May 1, 1981

** Vol 2, No 17, April 24, 1981

N - cited by New York, P - cited by Pennsylvania

TABLE 1 a

Small SO₂ Sources Listed as Area Source
in Table 1

	Source	Location	
P	1. Cities Services	Moundsville	W. Virginia
P	2. Dieckmar & Sons	(Moundsville)	W. Virginia
P	3. Taylor, Smith, & Taylor	Chester	W. Virginia
P	4. Triangle Conduit	Glendale	W. Virginia
P	5. U. S. Stamping	Moundsville	W. Virginia
P	6. Valley Camp Coal	Moundsville	W. Virginia
P	7. National Steel Corp's Brown Island	Weirton	W. Virginia
P	8. National Steel Corp's Brown Island	"	W. Virginia
P	9. Mainland Coke	"	W. Virginia
P	10. Wheeling Pittsburgh's Follensbee	Follensbee	W. Virginia

Annual Wet Deposition of Sulphur

Total Magnitude and Percentage Contribution of the 53 Sources

Cited by Pennsylvania and New York* to the Total

Sensitive Region	Total Wet Sulphur Deposition (g/m ² /yr)	Amount due to 53 Sources Listed	Amount due to 0.2 g/m ² /yr 'Background' Emissions	Amount due to Sudbury 1979	Amount due to Other Canadian Sources	Amount due to Other US Sources
Muskoka-Haliburton, Ontario	0.67	6.4	29.6	15.1	6.1	41.8
Algoma, Ontario	0.47	4.3	41.8	9.7	14.9	28.8
Lakehead, Ontario	0.28	2.9	70.8	1.3	4.8	19.9
Val D'or, Quebec	0.61	4.0	32.5	12.0	25.4	25.6
Adirondacks, N.Y.	0.83	8.4	23.9	4.1	5.7	56.4
West Pennsylvania	1.94	24.2	10.3	0.4	0.7	61.2

*"Federal Register", Vol. 46, No. 84, May 1, 1981
 "Inside EPA", Vol. 2, No. 17, April 24, 1981

NOTE: Model Predictions have been verified to be accurate within a factor of 2 with 60% of estimates within 35% of expected values.

714

LONG-TERM AVERAGE SO₄ CONCENTRATION

TOTAL MAGNITUDE AND PERCENTAGE CONTRIBUTION OF THE 53 SOURCES

CITED BY PENNSYLVANIA AND NEW YORK* TO THE TOTAL

Sensitive Region	Long-Term Average Sulphate Concentration (micrograms/m ³)	Amount due to 53 Sources Listed	Amount due to Sudbury 1979 Emissions	Amount due to Other Canadian Sources	Amount due to Other US Sources
Muskoka-Haliburton, Ontario	3.43	11.3	9.9	10.9	67.9
Algoma, Ontario	2.13	10.4	8.5	16.1	65.0
Lakehead, Ontario	0.98	11.0	3.8	14.7	70.5
Val D'or, Quebec	2.76	9.6	10.7	21.6	58.1
Adirondacks, N.Y.	4.59	13.1	4.3	10.2	72.4
West Pennsylvania	7.65	20.9	0.9	3.1	75.1

*"Federal Register", Vol. 46, No. 84, May 1, 1981
 "Inside EPA", Vol. 2, No. 17, April 24, 1981

Long-term Average SO₂ Concentration

Total Magnitude and Percentage Contribution of the 53 Sources

Cited by Pennsylvania and New York* to the Total

Sensitive Region	Long-term Average Sulphate Concentration to 53 Sources Listed (Micrograms/ m ³)	Amount due to 53 Sources Listed	Amount due to Sudbury 1979 Emissions	Amount due to	
				Other Canadian Sources	due to Other US Sources
Muskoka-Haliburton, Ontario	7.86	8.1	26.1	13.0	52.8
Algoma, Ontario	4.40	6.0	20.5	32.7	40.8
Lakehead, Ontario	0.96	8.9	5.1	21.9	64.1
Val D'Or, Quebec	6.98	4.5	20.7	45.7	29.1
Adirondacks, N.Y.	10.64	10.3	5.8	14.1	69.8
West Pennsylvania	33.35	28.2	0.3	1.7	69.8

*"Federal Register", Vol. 46, No. 84, May 1, 1981
 "Inside EPA", Vol. 2, No. 17, April 24, 1981

GRAHAM W.S. SCOTT, Q.C.

DEPUTY MINISTER

THE ONTARIO MINISTRY OF THE ENVIRONMENT

CLOSING REMARKS

HEARINGS ON INTERSTATE POLLUTION ABATEMENT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C.

JUNE 19TH, 1981

WE HAVE BEEN PRESENTING TECHNICAL EVIDENCE OF TRANSBOUNDARY POLLUTION FOR TWO REASONS. THE FIRST IS TO ILLUSTRATE TO YOU IMPACTS ON THE NEW YORK, PENNSYLVANIA, AND ONTARIO REGION. EVIDENCE OF THIS TYPE WILL BE MORE FULLY PRESENTED AND DOCUMENTED IN OUR WRITTEN COMMENTS TO BE SUBMITTED LATER. WE BELIEVE THAT THIS EVIDENCE IS DIRECTLY RELEVANT TO THE TERMS OF REFERENCE OF THIS HEARING.

THE SECOND REASON FOR OUR TESTIMONY WAS TO DISCUSS OUR EXPERIENCES IN CONSIDERATION AND CONTROLLING AGGREGATED SO_2 SOURCES IN RELATION TO TRANSBOUNDARY POLLUTION, AND TO SHOW YOU HOW WE HAVE USED LONG-RANGE TRANSPORT MODELLING IN THE CONSIDERATION AND CONTROL PROCESS.

SINCE THIS ISSUE IS CENTRAL TO THESE HEARINGS, AND SINCE IT IS COMPLEX, WE WANTED TO SHOW YOU THE DIFFERENT KINDS OF EVIDENCE WE HAVE ACCUMULATED FOR THE CONTROL OF TRANSBOUNDARY POLLUTION. WE REALIZE THAT THE EVIDENCE ITSELF MAY NOT ALL BE DIRECTLY RELEVANT TO THIS HEARING, BUT WE FEEL THAT OUR USE OF THE INFORMATION IN CONJUNCTION WITH MODELLING TO FORMULATE AND IMPLEMENT POLICY IS RELEVANT AS A "CASE STUDY". A FULL ACCOUNT OF THIS WILL BE SUBMITTED TO YOU, BUT I WOULD NOW LIKE TO BRIEFLY DESCRIBE WHAT OUR PHILOSOPHY IS AND GIVE YOU TWO EXAMPLES OF HOW WE ARE USING IT IN OUR POLICY MAKING PROCESS.

IN GENERAL, CONCERN ABOUT AN ENVIRONMENTAL ISSUE ARISES FROM SCATTERED EVIDENCE RELATED TO OBSERVATIONS. MANY OF THE RECENT AND CURRENT ISSUES ARE EMPLOYING MATHEMATICAL MODELLING TO HELP RESOLVE WHAT ACTION SHOULD BE TAKEN.

IN THE CASE OF LONGER-RANGE TRANSPORT, WE FEEL IT WOULD BE WRONG AS REGULATORS TO IGNORE THE AVAILABLE MODELS. A SUFFICIENT NUMBER OF THEM EXIST IN EUROPE AND NORTH AMERICA. INTERCOMPARISON OF MODELS WITH DATA SHOWS THAT THEY DO HAVE MERIT.

ON THE OTHER HAND, THE MODELS HAVE UNCERTAINTY IN THEIR RESULTS, AND DIFFERENT MODELS MAY DIFFER SOMEWHAT IN SOME OF THEIR RESULTS. UNDER THESE CONDITIONS, AS REGULATORS, IT WOULD BE UNWISE TO RELY SOLELY ON MODELS.

WE MUST REALIZE THAT ALL DECISION MAKING INVOLVES UNCERTAINTY -- THE DEGREE OF UNCERTAINTY DETERMINES THE VALUE OF A DECISION.

WE CANNOT DISCOUNT MODELLING RESULTS JUST BECAUSE THEY MAY DEViate FROM OBSERVATIONS. CLEARLY, THIS DEVIATION IS EXPECTED AND HAS TO BE ACCOUNTED FOR EXPLICITLY IN THE PROCESS OF DECISION MAKING. FURTHERMORE, IT IS IMPORTANT TO REALIZE THAT EMISSION CONTROL WILL RESULT IN A DEGREE OF REDUCTIONS IN CONCENTRATIONS AND DEPOSITION WHICH MAY BE DIFFICULT TO QUANTIFY.

THEREFORE, AS A DECISION MAKER, I HAVE TO ACCEPT THIS UNCERTAINTY IN MODELLING AND USE THE BEST TOOLS AVAILABLE TO ACCOUNT FOR UNCERTAINTY IN DECISION MAKING. IN ONTARIO, WE ARE NOW USING THE FOLLOWING PHILOSOPHY IN DECISION-MAKING:

1. WE DEVELOP LONG-RANGE TRANSPORT MODELS. THEN WE EXPOSE THE MODELS TO RIGOROUS AND OPEN PEER REVIEW, AND TEST THE MODELS AGAINST FIELD DATA. WE REQUIRE THE QUANTIFICATION OF UNCERTAINTIES.
2. AFTER THE FIRST ROUND OF THIS HAS BEEN COMPLETED, WE INSERT THE MODELS INTO THE REGULATORY PROCESS IN A GUIDELINE FASHION. THE UNCERTAINTIES IN THE RESULTS ARE DOCUMENTED AND DISCUSSED.
3. PRIOR TO MAKING A DECISION WHICH IS RECOMMENDED ACCORDING TO MODELLING RESULTS, WE ASSEMBLE AS MUCH EVIDENCE FROM OTHER INFORMATION SOURCES AS POSSIBLE.
4. THE IMPERATIVE ENVIRONMENTAL BENEFITS RESULTING FROM ACTION ARE WEIGHED AGAINST THE ECONOMICS AND ENVIRONMENTAL LOSS RESULTING FROM INACTION DUE TO UNCERTAINTY. A STEP-BY-STEP APPROACH EMPLOYING INTERIM ACTIONS MAY BE WARRANTED IF THERE IS AN IMMEDIATE NEED, BUT THE UNCERTAINTIES ARE LARGE. AS RESULTS BECOME MORE DEFINITE, FURTHER STEPS CAN BE TAKEN.

5. WHEN THE MODELS HAVE PASSED THE POINT OF EXHAUSTIVE TESTING, REVIEW, AND COMPARISON WITH OTHER DATA, THEY CAN BE INCORPORATED INTO THE REGULATORY PROCESS IN A BINDING WAY, KEEPING IN MIND THE NEED TO PERIODICALLY UPDATE THEM AS THE STATE OF THE ART PROGRESSES.

I WOULD NOW LIKE TO ILLUSTRATE HOW WE HAVE IMPLEMENTED THIS PHILOSOPHY IN THE CONTROL OF INCO AND ONTARIO HYDRO.

IN THE CASE OF INCO, WE HAD A LARGE BODY OF EVIDENCE SHOWING EFFECTS IN ONTARIO FROM SO_2 AND ACID DEPOSITION IN ONTARIO. WE ALSO HAD EVIDENCE WHICH INDICATED THAT SOME OF THIS DAMAGE COULD BE DUE TO INCO. ON THE OTHER HAND, WE HAD INDICATIONS THAT INCO WAS NOT THE SOLE CAUSE OF THE PROBLEM. THESE DATA WERE EXAMINED IN THE LIGHT OF THE LONG-RANGE TRANSPORT MODEL. THE CONSISTENCY BETWEEN MODEL RESULTS AND DATA GAVE US THE CONFIDENCE REQUIRED TO FURTHER EMPLOY THE MODEL TO PREDICT ENVIRONMENTAL BENEFITS TO U.S SENSITIVE AREAS, AS WELL AS THOSE IN ONTARIO AND THE REST OF CANADA, AND ENABLED US TO ASSESS BENEFITS AGAINST COSTS. AN INTERIM PROGRAM OF CONTROL WAS THEN IMPLEMENTED VIA REGULATIONS AND CONTROL ORDER.

IN THE CASE OF ONTARIO HYDRO, WE WERE FACED WITH CONTROL OPTIONS INVOLVING SIX FOSSIL-FUELED PLANTS, THREE OF THEM EMITTING MOST OF THE SO_2 AND NO_x . THE PLANTS WERE OF DIFFERING AGES, AND CONSTRAINTS EXISTED UPON THE TYPE OF CONTROL TECHNOLOGY WHICH COULD BE EMPLOYED BECAUSE THE PLANTS WERE SCATTERED ACROSS SOUTHERN ONTARIO, CUTS OF EMISSIONS AT ANY PLANT WOULD RESULT IN A DIFFERENT BENEFIT TO SENSITIVE AREAS IN THE U.S., ONTARIO, AND OTHER PARTS OF CANADA.

TO EVALUATE SYSTEMATICALLY THE COSTS AND BENEFITS OF SPECIFIC CONTROL OPTIONS, SOURCE RECEPTOR RELATIONSHIPS WERE DEVELOPED FROM OUR MODEL AND COMBINED WITH PLANT-BY-PLANT COST FUNCTIONS. LINEAR MATHEMATICAL ANALYSIS WAS THEN USED TO COMPUTE COSTS AND DEPOSITION REDUCTIONS.

CONCLUSIONS FROM THIS ANALYSIS WERE DISCUSSED WITH THE UTILITY, AND A REGULATION WAS ISSUED TO ESTABLISH THE INTERIM EMISSIONS CONTROL PROGRAM ON A SYSTEM-WIDE BASIS.

I THINK YOU CAN SEE THAT WE HAVE LEARNED A GREAT DEAL IN DEALING WITH OUR AGGREGATE SO_2 SOURCES, TO HELP SOLVE LONG-RANGE TRANSPORT POLLUTION PROBLEMS.

ON BEHALF OF ONTARIO, I THANK YOU AGAIN FOR GIVING US THE OPPORTUNITY OF PARTICIPATING IN YOUR DECISION-MAKING PROCESS. I THINK IT AUGURS WELL FOR RELATIONS BETWEEN OUR TWO NATIONS.

FROM THE EVIDENCE PRODUCED DURING THESE TWO DAYS, SOME TRUTHS ARE MANIFEST. TRANSBOUNDARY AIR POLLUTION FROM AGGREGATIONS OF SOURCES EXISTS. IT EXISTS IN THE CONTEXT OF THESE HEARINGS, FROM THE MID-WESTERN POWER PLANTS TO PENNSYLVANIA AND NEW YORK. IT ALSO AFFECTS ONTARIO. THE FACT OF TRANSBOUNDARY FLOW AS SHOWN HERE CANNOT BE IGNORED.

WE HAVE HEARD A GREAT DEAL OF TALK HERE ABOUT HISTORY, EMISSION HISTORY, METEOROLOGICAL HISTORY, HISTORICAL STATISTICS. THESE HAVE THEIR USES, BUT WE ARE IN A FUTURE-ORIENTED PROFESSION. WE CANNOT RE-CAST THE PAST, WE CANNOT PROTECT AGAINST HISTORY.

OUR EXPERIENCE LEADS ME TO BELIEVE THAT WE CAN HELP YOU APPROACH YOUR PROBLEM AND WE WISH TO ADVANCE THESE RECOMMENDATIONS IN THE SPIRIT OF COOPERATION WHICH IS TRADITIONAL BETWEEN OUR NATIONS:

THE FIRST NEED IS RECOGNITION. THAT'S WHAT THIS HEARING IS ABOUT. I AM CONFIDENT EPA MUST RECOGNIZE THE PROBLEM EXISTS, AS THE EVIDENCE OVERWHELMINGLY DEMONSTRATES. AS ENVIRONMENTAL PROTECTORS, WE MUST STAND GUARD FOR OUR CITIZENS. WE MUST NOT ALLOW ANY INCREASES IN EMISSIONS WHICH COULD CONCEIVABLY CAUSE CONTINUED OR FURTHER DAMAGE TO OUR ENVIRONMENT.

ONLY THEN WILL WE HAVE THE LUXURY OF TIME IN WHICH THE
SCIENTISTS CAN COMPLETE THEIR WORK, AND GIVE US THE BASIS FOR
A LONG-TERM AND LASTING SOLUTION TO THIS PROBLEM.

THANK-YOU.

SUDBURY ENVIRONMENTAL STUDY

AN ANALYSIS OF THE IMPACT OF INCO EMISSIONS ON PRECIPITATION QUALITY IN THE SUDBURY AREA

Report Number:

ARB-TDA 35-80

May, 1980



Ontario

**Ministry
of the
Environment**

The Honourable
Harry C. Parrott, D.D.S.,
Minister

Graham W. S. Scott, Q.C.,
Deputy Minister

Errata to MOE-ARB-TDA Report 35-80
"An Analysis of the Impact of INCO Emissions
on Precipitation Quality in the Sudbury Area"

1. Synopsis Table S3
corrected version should read:

	<u>Emitted (kg/day)</u>	<u>% Emissions Removed</u>
S	8.5×10^5	1.8

2. P.25,-line 4 should read:
"...estimated to be considerably smaller - i.e.
about 2% (1.5×10^4 kg/day)"
- line 10 should read:
"...deposition are: S,0.6%..."

3. P.36, Table 9
corrected version should read:

	<u>Emission Rate</u> <u>(kg/day)</u>	<u>Av. % Emissions</u> <u>Removed out to</u> <u>50 km on days</u> <u>when it was raining</u>
S	8.5×10^5	1.8

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AN ANALYSIS OF THE IMPACT OF INCO
EMISSIONS ON PRECIPITATION QUALITY
IN THE SUDBURY AREA

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Report Number ARB-TDA 35-80

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SYNOPSIS

Conclusions:

The main conclusions of this report may be summarized as follows, with the caution that they should be regarded as tentative until the full data base becomes available:

(1) The relative contribution of INCO emissions to the total wet-deposition of acids, sulfur, and a number of ions and trace metals in the Sudbury area (i.e., within about 50 km of the smelter) is small (with the exception of copper and nickel) - in the order of 10 to 20% - and depends on the weather system passing through the area. Warm fronts generally bring with them polluted air masses from Southern Ontario and the Eastern United States, and for acids, sulfur, and a number of trace metals, the INCO contribution appears to be about 10% of the total. For cold fronts, the percentage contribution from INCO is roughly twice as great. For copper and nickel, the smelter contribution appears to be roughly 40% of the total wet-deposition, regardless of the type of weather system. Note that these estimates of the relative contribution of INCO are based on the level of smelter emissions which occurred during the study period (see Table 9 of the report).

(2) Nevertheless a definite influence of the smelter plume on the local downwind quality of precipitation can be detected, especially for sulfates and trace metals. The smelter impact on precipitation acidity is less pronounced.

(3) During rainstorms, most particulate constituents (acids, sulfates, trace metals) are removed quite efficiently from the smelter emissions. Typically, 50% or more of these constituents may be removed within 50 km on the average rainy day. The percentage of the emitted sulfur that is removed by precipitation is much lower, mainly because this sulfur is largely in the form of sulfur dioxide which is subject to a low precipitation scavenging efficiency.

Introduction:

This is one of several reports prepared by the Ministry of the Environment about the impact of the Sudbury smelter emissions on the Sudbury basin and more distant areas, such as Muskoka-Haliburton. Various data analysis approaches have been taken in these reports, including a comparison of precipitation acidity, and bulk deposition, during the smelter operating and shutdown periods (see references 1 and 4 in the report). The present report concentrates on a detailed meteorological analysis of precipitation events which occurred when the INCO smelter was in operation, thus yielding certain quantitative conclusions about the smelter's impact which are not possible from a comparison of operating and shutdown period data alone. Both wet deposition and precipitation concentration of a number of substances are considered, because the aquatic environment responds primarily to deposition, while concentration may be more relevant to the terrestrial system. Data analysis is focussed on five areas: 1. An evaluation of background concentrations (long range transport component into the region) associated with different types of frontal passage. 2. The relative contribution of local and distant sources to the local precipitation quality. 3. The dependence of pollutant concentration in precipitation on distance from the source due to the interaction of plume and precipitation. 4. The deposition pattern of INCO emitted pollutants. 5. The contribution of local emissions to total wet deposition in the Sudbury area.

An analysis is carried out on precipitation samples from 31 events in August and September, 1978 and from June to October, 1979, collected largely within a 50 km radius of the INCO smelter. At the time of writing, the above periods included most of the chemically analysed data available from the Sudbury Environmental Study's event precipitation sampling network with INCO in operation (there was a lengthy shutdown due to a strike at the smelter from Sept. 15, 1978 to June 4, 1979). The results are thus of a preliminary nature, since the collection and chemical analysis of samples is still in progress. For example,

deposition by snow or convective storms is not considered at all. Final conclusions will only be possible when the full data base becomes available later this year, and will be reported in November of 1980.

Analysis Summary:

It became evident quite early in the analysis that the composition chemistry of a particular precipitation sample is largely determined by two factors: the type of weather system with which the precipitation is associated, and whether or not the sample is collected downwind of the smelter during the event under consideration.

The weather system is important because warm frontal precipitation is associated with air masses that have crossed industrialized urban areas of Southern Ontario and Eastern United States, whereas cold frontal passages are usually accompanied by the influx of relatively clean air from Northern Canada. Table S1, for example, summarizes some differences in background precipitation chemistry for the 31 events under study.

Table S1⁺⁺: Mean Background Concentration

(except for pH, all units in mg/l)

Type of Front	pH*	SO ₄ *	NO ₃ *	NH ₄ *	Fe*	Cu	Ni	Pb*	Zn
Warm	4.2	4.8	0.61	0.61	0.039	0.0031	0.0014	0.012	0.015
Cold	4.6	1.4	0.21	0.25	0.022	0.0040	0.0016	0.0065	0.013

The averages shown in the above table were obtained from precipitation samples which were clearly identified as not interacting with smelter emissions. An asterisk identifies those parameters for which there was a statistically significant difference (at the 95% confidence level) between the warm and cold frontal mean concentrations. Note that acids (as indicated by the pH), as well as

++ Based on Table 3 Of the report

other constituents associated with long-range transport (SO_4 , NO_3 , Pb), occur at significantly higher concentrations in warm frontal precipitation, whereas species characteristic of smelter emissions (Cu, Ni, Zn) occur at comparable background levels in both warm and cold frontal air masses.

In view of the above results, it is clear that the relative contribution of smelter emissions to the precipitation quality and wet-deposition of many constituents will vary with the type of weather system. The smelter impact on the precipitation quality was determined by carrying out a sector analysis -i.e., by identifying, with the aid of local wind data and other information, those samples downwind of the smelter which could have potentially been affected by smelter emissions during the course of the storm, and comparing their precipitation concentrations with concentrations in the other "background" samples, during the same storm. Table S2 illustrates the average percentage elevation, above background levels, of plume sector sample concentrations for the parameters in Table S1. Note that pH has been converted to H_f , the free hydrogen ion concentration, using the relationship $\text{H}_f = 10^{-\text{pH}} \times 10^3$ (mg/L).

Table S2⁺⁺: Percentage Elevation (above background) of
Average Plume Sector Concentrations

Type of Front	H_f	SO_4	NO_3	NH_4	Fe	Cu	Ni	Pb	Zn
Warm	37	60*	35	33	104*	800*	914*	65*	45
Cold	94*	126*	37	46	144*	627*	894*	98*	60

⁺⁺ Based on Tables 4 and 5 of the report

As indicated by the asterisks (plume sector concentrations significantly higher than background, at the 95% confidence level), in precipitation samples within the plume sector, the smelter influence is clearly evident for sulfates and most of the trace metals. It is interesting to note that for free hydrogen ions, no statistically significant smelter impact can be detected for the 16 warm frontal events included in the present study.

The sector analysis is extended in the report to examine two additional questions:

(1) What percentage of the smelter emissions are removed by wet deposition within the Sudbury area?

(2) On a longer-term basis, what is the contribution of INCO emissions to the total wet deposition of acids, sulfur, trace metals and other contaminants in the Sudbury basin?

The main results are summarized in Table S3.

Table S3⁺⁺: Wet Deposition of INCO Emissions Within
a 50 km Radius of the Smelter

	Emitted	Deposited	% Emissions	%INCO Contribution to Total Wet Deposition	
	(kg/day)	(kg/day)	Removed	Warm Fronts	Cold Fronts
H ⁺	7.2×10^2	5.7×10^2	79	9	21
S	1.7×10^6	1.5×10^4	0.9	12	31
Fe	6.1×10^2	3.5×10^2	57	11	18
Cu	3.3×10^2	1.7×10^2	52	44	38
Ni	1.4×10^2	7.1×10	52	42	38
Pb	3.2×10^2	1.0×10^2	31	10	20
Zn	1.1×10^2	1.3×10^2	118	11	13

++ Based on Tables 9 and 10 in the report

Regarding the first question, it can be seen from column 4 of the above table that acids and most trace metals are removed very efficiently from the smelter plume. The S emitted by the smelter is predominantly in the form of SO_2 , which is expected to have a relatively low scavenging rate - hence the low percentage removal for sulfur. Actually, the values given in Table S3 for percentage of INCO emissions removed within 50 km are probably upper limits, since they are based on the 381 m stack emissions only. Low-level smelter emissions, which also contribute to the wet deposition, should have been added to the 381 m stack values in our calculations, but were not, because they have yet to be quantified properly. It must be pointed out that there is more uncertainty in the deposition rates for H_f and S than for the metals in Table S3, and conclusions about the deposition of these two parameters should be at present regarded as very tentative. It must also be pointed out that Table S3 shows the percentage of the smelter emissions removed by wet deposition on the 31 days under consideration during which it was raining. If an estimate of the corresponding annual average percentage is desired, the values in column 4 must be modified, since it does not rain on every day of the year. An approximate annual average percent removal can be obtained by assuming that precipitation falls every third day, and then multiplying the corresponding numbers in column 4 by one-third. The reader should also be cautioned that this report considers wet deposition only. Smelter emissions will be also removed by other processes not considered here, such as dry deposition, so the figures in Table S3 should not be used to estimate the percentage of the INCO emissions which are not removed, and leave the study area as long-range transport.

Turning now to the contribution of INCO emissions to the total deposition in the study area, column 5 of Table S3 shows that, for warm frontal storms, the smelter contributes in the order of 10% of the total deposition for most of the parameters shown, with the exception of Cu and Ni (where the contribution is considerably greater). For cold frontal storms, the smelter share of the total deposition is

roughly twice as great as for the warm frontal cases, except for Cu and Ni (where it is roughly the same). For an average of all types of storms in the Sudbury area, the INCO contribution to the total deposition is expected to be within the range of values shown in Table S3 (i.e. about 40% for Cu and Ni, and 10-20% for most other contaminants, including acids).

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1. Introduction

As part of the Sudbury Environmental Study, the Air Resources Branch (ARB) has been very active in precipitation monitoring in the Sudbury area. The primary objective of this program component is to assess the impact of local sources on precipitation quality and to determine the long term wet deposition pattern in the greater Sudbury area.

During part of 1978 and 1979, the local sources, i.e. INCO and Falconbridge, were not operating, either due to scheduled shutdowns or labour disputes. Immediately after the 1978 shutdown period, a preliminary report (1) was published in which the precipitation network data were evaluated in light of the smelter operating conditions. In that report, it was felt that because of the limited data available, definitive conclusions regarding local source impact could not be made. Since then, a large amount of additional data has been collected, and new analysis techniques have been used for assessment of the fate of the local emissions.

In the present report emphasis will be given to data collected during August-September 1978, and during June to October 1979, for periods when both INCO and Falconbridge were operating. The contributions due to background (i.e. long range transport) and local sources to precipitation quality will be determined and the long term wet deposition pattern in the greater Sudbury area will be estimated. Discussions will be focussed on the INCO operation. Both concentration and deposition considerations are included in this report, because the concentration may be more relevant to terrestrial affects, while the aquatic environment responds primarily to deposition. However, no attempts are made here to interpret the implications of the established values in terms of effects as this is not the mandate of the Air Resources Branch component of the Sudbury Environmental Study. The results presented here should be regarded as preliminary only since the work involved extrapolation of limited seasonal data to a yearly

basis. The full data set will be available when Sudbury Environmental Study (SES) field activities are completed and in the final Sudbury Environmental Study Report (scheduled for November of 1980), refinements in the analysis will be made, together with a discussion of effects of the Falconbridge source.

2. The Networks

2.1 History, Objectives and Instrumentation

Two different precipitation monitoring networks have been operated in the Sudbury area as part of the Air Resources Branch commitment to the Sudbury Environmental Study.

The first- a cumulative precipitation monitoring network-was designed to assess the long term, large scale, wet deposition field of various substances in the Sudbury area. The network consists of 18 Sangamo Type A wet-only-deposition collectors and 4 Aerochem Metric wet-only collectors. These samplers are distributed throughout the region within a radius of 125 km from Sudbury. The location of the sites can be seen in Figure 1. Sampling began in December of 1977 with ten stations and expanded to its full compliment in mid-1978. The network has operated typically on a monthly collection basis. No further reference will be made in this report to the cumulative network since the balance of this report deals solely with data from the second network. The cumulative network is described here only to provide a brief overview of the entire precipitation monitoring program of the Air Resources Branch. Results of this network will be presented in a future Sudbury Environmental Study report.

The second network is an event precipitation sampling network. It was designed with the objective of assessing the relative impact on local precipitation quality of local as well as more distant sources. Sample collection is carried out on a twenty four hour event basis. Samplers are concentrated primarily within a radius of 50 km from Sudbury. The network was started in late June of 1978. Throughout its operation the number and location of samplers has varied considerably. Typically 20 to 25 samplers have been operated during the summer months and 10 to 15 during the winter. A summary of the period of operation of all samplers is given in Figure 2. Actual sampling locations

(except for the distant samplers at Charlton Station, Ramsey, Thessalon and Blind River) are shown on Figure 3.

The instrumentation for the event network is relatively simple. It consists of a wide-mouthed bucket (42.4 cm dia.) mounted approximately one metre above ground level. A new, high-density polyethylene bag is inserted inside the collector daily. This bag provides a clean, untouched container for precipitation collection, and eliminates the need for washing and leaching of the collector. In the summer of 1979, custom-made bags were introduced into the network. These differed from the bags used previously in that they contained a diagonal seal across their width. This seal and the small opening left near one side, formed a funnel when the bag was inserted in the collector, thus minimizing evaporative losses from the sample. An ordinary bag insert (without the seal) was used in the winter.

2.2 Sample Handling

Event samplers are maintained daily. Using disposable plastic gloves, operators change the bag insert at typically 0800 hrs, after which time they remain open for the entire collection period. If no precipitation occurs during the collection period, the bag is discarded. If precipitation does occur, the bag is removed, a bottom corner is cut, and the sample is transferred to two 450 ml polystyrene bottles and one 60 ml polyethylene bottle. The former bottles are submitted for laboratory analysis of major ions while the latter are spiked at the field office with 0.5 ml of 5% nitric acid and submitted for trace metals analysis. A 50 ml aliquot is taken for "field" pH measurement. Any excess sample is measured for volume and discarded.

At sampling locations not staffed by Sudbury Environmental Study personnel, the samples are stored in refrigerators and collected at least once per week. They are then taken to the Sudbury Environmental Study field office where

a 50 ml aliquot is taken for "field" pH measurement, the total volume is determined, and the bottles for metals analysis are spiked with nitric acid. All samples are refrigerated and submitted to the Laboratory Services Branch in Toronto once per week.

In the event that the amount of precipitation collected is less than 1.05 litres, definite sample handling criteria are followed to obtain the most useful information from the limited sample. These criteria are summarized in Appendix 1.

2.3 Chemical Analysis

The Precipitation samples are submitted for chemical analysis to the Laboratory Services Branch of the Ontario Ministry of the Environment in Toronto. Samples stored in the polystyrene bottles are analyzed for: pH, acidity, SO_4 , NO_3 , NH_4 , Ca, Na, K, Mg, Cl, F; and the samples from the acidified polyethylene bottles for Fe, Ni, Cu, Pb, Zn, Al, Cr and Cd. The samples are not filtered prior to analysis. Conductivity is also measured to check the ionic balance. The analysis methods used are summarized in Table 1 together with their corresponding detection limits. Concentrations of NO_3 and NH_4 are expressed as N- NO_3 and N- NH_4 . In the beginning of the sampling program, samples were analyzed also for Br and Si, however these were later deleted from the parameter list because they were consistently below detection limits. Note also that in many of the samples identified in the present report as "background", Cu and Ni occurred at concentrations below the detection limits of the analysis method used. In these cases, the data in Appendix 2 were given as being at the detection limit (0.001 mg per liter).

It should be pointed out here that pH is a measure of the free acidic component of precipitation due to strong mineral acids (mainly sulfuric and nitric). It is equal to the negative logarithm of the free hydrogen ion concentration (in

moles per litre). Total acidity, on the other hand, which is related to the total hydrogen ion, is a measure of the capacity of the precipitation sample to neutralize base, and is made up of the contribution due to strong acids, weak acids (carbonic acid, organic acids), hydrolyzable metallic salts, etc.

Free hydrogen ion H_f and total hydrogen ion H_t concentrations (in mg per liter) can be calculated according to the following expressions:

$$[H_f^+] = 10^{-pH} \times 10^3$$

and

$$[H_t^+] = \text{Acidity (in mg Ca CO}_3 \text{ per liter)} / 50$$

2.4 Quality Control

2.4.1 Sample Screening

Integrity of the event precipitation data is guaranteed by a three-step quality control program, viz:

1. Collected precipitation samples which have been contaminated by visible organic material or particulates are discarded immediately.
2. Results of the chemical analysis are screened manually before being placed in the data base. They are divided into two subsets according to the quality of the data. Details of the criteria for categorizing the data are given in Table 2.
3. Data from the two data base subsets are further evaluated for quality in light of the data from all other station samples collected during the same individual events.

Specific details of the third step are given below in Section 2.4.2..

All accepted data are placed in the SES data base with appropriate comments (for later evaluation on an event basis).

2.4.2 Data Screening

Placement of data in the "problem data" category does not necessarily eliminate it from further use. If it can be shown that during a given event, the data for some of the chemical parameters in a particular "problem" sample are reasonable, they will be accepted. However close scrutiny is required before the data will be accepted. Similarly, data in the "accepted data " set may not necessarily be included in final calculations.

In general, the following criteria have been used in the data screening process.

1. Data corresponding to the upper 2% range are singled out initially as outliers. They may be included in the final analysis provided that this does not change the overall pattern during particular events.
2. Most of the data associated with sample volumes less than approximately 140 ml (1 mm depth) were not included in the analysis. Concentrations for these samples were generally very high, which may be partly due to genuine effects (e.g., different scavenging mechanisms in light precipitation), and partly to the relatively greater importance of errors due to evaporative losses, dryfall contributions, and sample-container interactions in low-volume samples. Our understanding of these phenomena is not sufficient to enable a proper interpretation of the data in the light of plume vs. background effects.
3. In the assessment of plume impact on local precipitation quality, a sector of precipitation affected by the plume has to be defined and this selection process will be discussed in Section 3.2.2. After determining the plume sector, data from stations falling within and outside of the sector are evaluated separately for consistency. Due

to possible contamination problems which might not have been recognized before sample submission, atypical data which would result in an anomalous pattern are deleted-e.g. a single extremely high concentration value among other low ones outside the plume sector may be due to contamination associated with site specificities, or to chemical analysis errors.

3. Results and Discussion

3.1 Data Presentation

Following the procedures to be discussed in later sections, thirty-one events, each consisting of data from at least 3 stations, were selected from periods when both INCO and Falconbridge were in operation. These events include samples from August to September, 1978 and from June to October, 1979. These are primarily summertime events and the raw data can be found in Appendix 2.

3.2 Data Analysis Approach

In the preliminary analysis of the 1978 shutdown data (1), it was concluded that (a) the temporal and spatial variability of precipitation pH and acid loading in the Sudbury area can be very large, (b) there is a significant acid loading due to precipitation in the Sudbury area, which can only be attributed to long range transport and (c) final conclusions regarding the impact of smelter emission on precipitation chemistry in the Sudbury area will have to await a more detailed meteorological analysis as well as an examination of supplementary data (e.g. trace metal concentrations). A number of these additional analyses will be discussed in this report.

It has become quite apparent that the background contribution of wet deposition due to long-range transport is not only large, but also varies with the origin of the air mass arriving in the Sudbury area. It was found that in order to assess the smelter contribution relative to that of the imported materials, events had to be first classified according to whether they were associated with warm or cold frontal passages. Sector analysis then singled out samples which were probably affected by local sources during particular events under consideration. The data for both the meteorological stratification and sector analysis are summarized in Appendix 3.

3.2.1 Meteorological Stratification

Information regarding frontal passages was extracted from 6-hour synoptic weather maps. Many events were examined. Some are quite straightforward in terms of classification into cold or warm frontal passages. Others, with the low pressure system centred in the Sudbury area, are somewhat ambiguous because they generally correspond to complicated multiple front or occluded frontal situations. This is reflected in drastically different background concentrations of samples collected in different sectors (or directions) within the network area. Only 31 events for which distinct meteorological assignment of frontal passage could be made (out of a total of 52 events during the study period) are included in this evaluation. In Appendix 3, events are designated numerically according to the sequence of sampling dates. Some pertinent information regarding precipitation time, amount and type is also listed. The above information and wind directions are extracted from hourly surface weather records at Sudbury airport (ground level) and the MOE meteorological tower (250 ft. level).

3.2.2 Sector Analysis

In general, there are two ways to sample precipitation for purposes of source impact evaluation. One involves placing samplers directly underneath the plume once its position is located. Another is to place samplers in a pre-set pattern with subsequent stratification of the sample to identify the plume contribution. The former is a more direct method. However, it is labor intensive and can become very expensive if designed to include a significant number of different storm types. The latter approach is somewhat indirect but is logistically simpler, and was chosen for the present long-term study.

Network design therefore dictates that a careful stratification of samples, according to whether they could be potentially affected by the plume or not, be made before meaningful statistics can be obtained. In selecting the plume sector the most important criterion used was that the sector had to be downwind of the source (as indicated by the surface and upper-level winds). In addition, the

plume sector was verified by examining the data for some of the following characteristics:

1. The SO_4 , Ni or Cu precipitation concentration (or the SO_4/NO_3 ratio) was seen to be elevated.
2. Continuous SO_2 monitors (operated by the NE Region) near some of the samplers, recorded elevated SO_2 concentrations during the storm.

Generally, samplers identified by elevated SO_4 , Ni, Cu or SO_2 concentrations were also within the plume sector established on the basis of the wind data alone.

The final sectors selected are summarized in the 11th column of the Tables in Appendix 3. They correspond to the area potentially affected by the plume, and should not be confused with the actual physical width of the plume since, during a particular event, the plume may have been meandering over a considerable area due to wind shifts. Usually the sectors are less than 120° wide. Some examples of plume sectors are shown in figures 4 and 5.

3.3 Data Interpretation

After following the two-step process in establishing the frontal passage and plume sector, the data were examined for the following:

1. An evaluation of background concentrations (i.e. the long range transport component into the region) associated with different types of frontal passage.
2. The relative contribution of the local and distant sources to the local precipitation quality.
3. The dependence of precipitation concentration due to the local source as a function of distance from the INCO source.
4. The deposition pattern of INCO emitted pollutants.
5. The contribution of local emissions to total wet deposition in the Sudbury area.

The following sections include both data analysis methods and findings based on the 31 summer/autumn events.

3.3.1 Background Component Evaluation

Based on the 31 events selected for discussion in this report, wind roses for both the cold and warm fronts were determined. It was found that during warm frontal passages, the most prevalent wind directions were southerly and southwesterly, whereas for the cold frontal cases, the predominant directions were northwesterly and northerly with a smaller southerly component.

By grouping the concentration data outside the plume sector for the warm and cold frontal passages, the statistics in Table 3 were obtained. The first column gives the parameter of interest. The fourth and seventh columns show the number of events used in the calculations. The second and fifth columns give the average concentrations based on area means associated with individual events. The third and sixth columns give the corresponding one standard deviation for the warm and cold frontal cases respectively. The eighth column indicates the ratio of the average cold and warm frontal background concentrations and the last column is a summary of the student-t statistics (a normal distribution of the parameters was assumed). For the sample size used in our calculations any $t \geq 12.06$ corresponds to a statistically significant difference between the two types of frontal passage at a 95% confidence level. Several observations are quite apparent:

1. The acid-base equilibrium related parameters, eg. H_f (free hydrogen ion), H_t (total hydrogen ion expressed as acidity) SO_4 , NO_3 and NH_4 , and F are quite different for the precipitation samples associated with the two types of frontal passage. This reflects the different origins of air masses associated with warm and cold fronts. For warm fronts, the air masses generally pass over the highly industrialized NE United States and Southern Ontario before arriving at the study area. For cold fronts, the origin of the air masses is generally northern Canada.
2. Most heavy metal concentrations are not statistically significantly

different for the two types of frontal situations.

3. In the case of Pb and Cd the difference between background concentrations associated with the two frontal types is statistically significant, suggesting that long range transport of Pb and Cd may be significant. This is in accord with the size characteristics of Pb, and Cd which are primarily associated with fine particles of mass median diameter less than 1 μm . Hence, like sulfates, they have a relatively long atmospheric residence time.
4. Other parameters such as Ca, Fe and Al, which are soil-related, exhibit statistically significant differences at the 95% confidence level for the two types of fronts. This may be a reflection of differing wind speeds, and hence re-entrainment of dust, during cold and warm frontal passages.

3.3.2 Relative Impact of Local and Imported Components to Local Precipitation Quality

Concentration data are grouped according to sampling date and frontal passage, and are tabulated in Appendix 4.

Note that the EXSS (i.e. additional) concentration in Appendix 4 is NOT calculated by subtracting the overall mean background concentration from the mean plume sector concentration. Rather, for each individual event, the mean background concentration is subtracted from the concentration of each sample within the plume sector and these differences are then averaged to obtain the mean additional plume sector concentration for that particular event. In some cases (less than 5% of the data), the above subtraction leads to negative values, due to random errors associated with sampling and analysis. These values have no physical significance, and are replaced by zeros. It is felt that this substitution of zeros for negative values is appropriate for parameters associated with smelter emissions, but for those parameters which are primarily due to long range transport and/or local contaminants such as windblown dust (e.g. NO_3 , Ca, Mg etc.), the negative values might be real (because of variability in local site characteristics for example).

Therefore the additional concentrations shown for the latter parameters probably overestimate the true plume contribution.

The tables in Appendix 4 reflect the spatial and temporal variabilities of the local precipitation data. For a particular event, the background spatial variability is typically smaller than that seen in the plume sector. This is what one would expect downwind of a point source.

Summary data showing the mean background and plume concentrations for the two types of frontal passage are given in Tables 4 and 5. Also the mean additional concentration, due to interaction of plume with precipitation, calculated according to procedures described above, is given. The ratios of the mean plume concentration to the background concentration are given under heading "B/A" together with the corresponding paired-t statistics. Due to the lower background associated with the cold fronts, their B/A ratios are generally higher than those for the warm frontal cases. The largest ratios of plume to background concentrations are observed in the cases of Cu and Ni. This is not unexpected because of the nature of the smelter emissions. SO_4 , and some trace metals, e.g. Fe, Cu, Ni, Pb, and Cd are consistently higher in the plume sector and the differences are statistically significant at the 95% confidence level. The relative magnitude of the additional concentration and background concentration is expressed as C/A in the last column.

In Table 6, additional plume sector concentrations are compared for cold and warm frontal cases. The second to last column in this table gives the ratios for these two. It is noted that for most parameters, e.g. H_2f , acidity, Cl, Na, Cu, Ni, Zn and Cd, the additional plume sector concentration differed by less than 20%. In most other cases, the ratios are less than unity, suggesting that there might be higher additional concentrations in the warm frontal cases. For H_2f , SO_4 , NO_3 , NH_4 , Pb and F, this could possibly mean that scavenging of plume constituents is more efficient due to the nature of the air mass, which originates from the

industrialized south. The results for soil-related materials (e.g. Ca, K, Mg, Fe, and Al), and Cr are not easily explainable, and are being analysed further. The last column is a summary of the paired-t statistics. In none of the cases is the difference between cold and warm front additional plume sector concentrations statistically significant at the 95% level. This adds credence to the approach used in the remainder of this report -i.e., pooling of warm and cold frontal information for calculating the local source impact.

3.3.3 Dependence of Plume Contributed Concentration on Distance from the INCO Source

Based on the criteria given in Section 3.2.2., plume sectors originating from both the INCO and Falconbridge complexes were established for individual events. In cases where these sectors overlap complications may arise because some sampling stations could have been affected by both sources. Therefore the relative impact due to Falconbridge alone was estimated. Precipitation data obtained from mid-September of 1978 to early June of 1979 (when INCO was on strike) were examined. Due to the sparsity of sampling stations in the vicinity of Falconbridge (especially to the north), the effects of Falconbridge alone on local precipitation could only be assessed in qualitative terms. In general it was found that for equal distance from the two sources, the additional concentration due to Falconbridge alone is typically one-tenth or less of that due to INCO. This is in accord with the relative emission strengths of the two sources. Despite the fact that the relative effect of Falconbridge vs. INCO is small, all the data from samples which could have been affected potentially by both sources were excluded from the assessment of the functional dependence of additional plume concentration on distance from INCO only data designated by "I" and "N" in Appendix 2 are used in the calculations.

Table 7 summarizes the additional concentration due to INCO as a function of distance from the source. Samplers were grouped together according

to different distance intervals from INCO-e.g. 3-6 km, 9-11 km, 14-18 km, 21-27 km, 31-32 km and 35-50 km-to obtain the long term average data pattern. Due to that fact that all samples from far downwind distances (e.g. 35-50 km) could be potentially affected by both sources, they were excluded in the analysis. In Table 7, the number of values included in each distance interval is given as "NN" together with the corresponding mean concentration and standard deviation. The mean additional concentrations correspond to the averages of all event additional concentrations in a given interval calculated as described in Section 3.3.2. From these values, it is seen that the variability within the plume sector is quite large even for a single distance interval, mainly due to plume meandering, spatial and temporal variations in the precipitation rate, and changes in the background component from one event to another.

These additional concentration data have been plotted on semi-logarithmic and linear co-ordinates versus distance from INCO. In general, it was found that the data are better represented on logarithmic co-ordinates (see Table 8) and therefore the concentration data are log-transformed before plotting against distance, as in Figures 6 to 24. Each data point in the figure represents the mean of a group of original data points falling within a given distance interval.

In Table 8, both the linear correlation and regression coefficients (according to $Y = \underline{A} + \underline{B} X$) are given for logarithmic and linear concentration co-ordinates.

For results which can be reasonably represented by a regression equation, the best fit line is shown in the figure together with the correlation coefficient and regression equation. The results can be categorized into five groups.

1. SO_4 decreases slowly with distance from the source. This may indicate that SO_4 scavenged from the plume is replaced by SO_4 generated from the oxidation of SO_2 . Such an effect would require a relatively high $SO_2 \rightarrow SO_4$ oxidation rate under precipitation conditions.
2. Both the H_f and acidity (H_t) patterns are somewhat irregular and may reflect complex acid-base equilibrium relationships, or the

formation of sulfuric acid due to oxidation of SO_2 in the plume.

3. All trace metals concentrations fall off exponentially with distance from the source although the fits for Al and Zn are relatively poor. Using the best-fit regression lines in the figures together with detection limits for our chemical analysis methods, distances beyond which no plume effects can be detected (i.e., where concentrations have fallen to detection limits) were extrapolated from the data. These are also given in Table 8. In general, for metals showing high correlation coefficients, the data suggest that, on average, the smelter impact does not extend beyond 100 km. It should be stressed that because of the logarithmic nature of the fit, a small fluctuation in the data could lead to a large discrepancy in the distance intercept.
4. Other parameters such as NO_3 , NH_4 , Ca, Mg, K and Na show irregular patterns and very poor linear correlation coefficients. This is attributed to the randomness associated with long range transport or local contamination of these elements.
5. No explanation can be given for the pattern exhibited by Cl and F.

3.3.4 Long Term Deposition Pattern of INCO Emissions

The additional concentration data discussed in section 3.3.3 were further analyzed to estimate the long term deposition pattern of the INCO emissions in the greater Sudbury area. Attention was focussed on the emittants of major interest i.e. S, Fe, Cu, Ni, Pb, Zn and H_2F .

Total deposition out to 50 km from INCO was calculated according to the following expression:

$$\text{DEP}_{\text{av}} = D_{\text{av}} \sum_{i=0}^{50 \text{ km}} (C_{\text{add}} \times A_{\text{plum}})_i$$

where

DEP_{av}	=	average daily deposition through wet scavenging
D_{av}	=	average daily precipitation depth
C_{add}	=	average additional concentration due to interaction of plume and precipitation

A_{plum} = plume sector area

From the 31 events included in this report, an average of daily precipitation depth (9mm) was obtained by averaging all the daily mean sample volumes. Also, an average angle of 105° was obtained for the sector width in the 31 events. Using the above data, as well as the regression equations defined in Table 8, the average wet deposition per precipitation day of smelter emissions out to 50 km from the source was calculated. The results are given in column 2 of Table 9 as kg deposited per precipitation day.

It should be noted that the values for sulfur (as sulfate) and free hydrogen ions were not based on the regression equations of Table 8, because the correlation coefficients were quite low. Rather, average additional concentrations of 2.23 mg l^{-1} and 0.0277 mg l^{-1} were used in the calculations. These values were obtained by averaging all the individual additional concentrations of samples collected inside the plume sector from all event days. The original data cover an area defined by a radius of 30 km and therefore the results with extrapolation to 50 km must necessarily be approximate.

In order to estimate the fraction of emitted pollutants that is scavenged by precipitation on a rainy day, average daily emission estimates of these parameters are necessary. There were no in-stack measurements at the INCO 381 m chimney in August-September, 1978 and June-October, 1979. However, SO_2 monthly emission rates (calculated by mass balances) are available. During the study period these ranged from an average of 658 metric tons per day (for July and August, 1978), to a high of 2320 tons per day (for September 1979). From such data, an overall average daily SO_2 emission rate of $1.7 \times 10^6 \text{ kg per day}$ was obtained by weighing the emission rate for each month in our study period by the number of plume sector samples collected during that particular month. The particulate emission rates during the study period could then be estimated using values of particulate - to - SO_2 ratios measured in the INCO plume near the 381 m stack in airborne studies carried out in 1976 and 1977, (2) and again in September, 1979.

Column 3 of Table 9 shows emission rates of the substances of interest, obtained by multiplying their particulate-to-SO₂ ratios by an average SO₂ emission rate of 1.7 X 10⁶ kg per day. Also shown in brackets in column 3 are the number of experimental values for the parameter/SO₂ ratio on which the average emission rate is based. Note that emission rates can vary over a wide range, mainly due to process variability (column 4).

From columns 2 and 3 of Table 9, the percentage of each parameter removed on average during each precipitation day by wet deposition out to 50 km from INCO can be estimated. The results are shown in column 5. It must be emphasized that the estimates in column 5 are based on the 31 events reported here, and thus only apply to that subset of days when precipitation was occurring. Since it does not rain on every day of the year, these results must be modified if an estimate of the corresponding annual average percentage is desired. A good approximation can be obtained by assuming that precipitation occurs every third day, and multiplying the numbers in column 5 by one-third to obtain the annual average percentage of emissions removed by wet deposition.

The following observations are of interest:

1. The percentage of the emitted sulfur that is deposited by precipitation within about 50 km of INCO is quite small. This agrees with the results of a study carried out by Wiebe and Whelpdale of the Atmospheric Environment Service some years ago (3).
2. The results for H_f have already been qualified above, but it should be further pointed out that due to chemical transformations in the plume, sulfuric acid is probably being continuously formed from SO₂ as the plume travels downwind. Thus, the emissions have a "potential acid content" in excess of the "H_f emission rate" shown in Table 9, i.e. more H_f can be deposited, and this should be kept in mind when considering the value in column 5 for H_f.
3. The percentage of trace metals deposited by precipitation is quite high, suggesting a relatively efficient scavenging process (again, in

agreement with the Atmospheric Environment Service measurements (3)). In fact, for some parameters the percentage of the emissions removed by wet deposition seems suspiciously high, since it generally rained for less than one-third of the 24-hour period in our data set, while emissions continued, of course, for the total period. Admittedly, as indicated by the standard deviations in the emission rates shown in Table 9, there is a considerable uncertainty in the actual emission rates that should have been compared with the measured deposition values, and this could partly explain the results. Furthermore, no account was taken of the low-level emissions from INCO, which have not been properly measured to date, but according to some estimates the particulate emissions could be of the same order of magnitude as those from INCO's 381 m chimney. Since our samplers were exposed to the effects of both 381 m stack and low-level emissions, the total emission rate from both sources should properly be used in computing column 5 of Table 9. Finally despite the fact that precautions were taken to obtain wet-only samples, there is a possibility that some dry deposition may also have occurred during the sampling period, especially if low-level emissions passed over the sampler. The importance of the contribution from this effect is hard to evaluate at present.

3.3.5 Contribution of INCO Emissions to Total Wet Deposition in the Sudbury Area

The data presented in Table 9 are further arranged to yield information on the wet deposition due to local sources relative to the total (local + long range transport) deposition in an area defined by a radius of 50 km from INCO. This was done separately for the warm and cold frontal cases by multiplying the appropriate concentration, area and precipitation depth (9mm). The average plume-affected sector was again assumed to be 105° wide. The mean background concentrations used are those reported in Tables 4 and 5. Table 10 shows the wet deposition due to

local sources (taken from column 2 of Table 9), as well as the background contribution. In columns 5 and 6 of this table, the local contribution is expressed as a percentage of the total value. As expected, the relative contribution of local sources is generally higher for events associated with cold frontal passages. Typically, local contribution amounts to less than 20% of the total deposition to the study area, with the exception of Cu and Ni, where the local contribution as high as 45% (-this figure could be even higher, since, as pointed out in Section 2.3, Cu and Ni concentrations in many background samples were assumed to be at the detection limit, whereas in fact they were below the detection limit). Note that the numbers in columns 5 and 6 of Table 10 apply to the level of smelter emissions obtaining during the study period. The smelter contribution to the total wet-deposition at other emission rates would of course be different, and is expected to increase as the emission rate increases. Mathematical models currently being developed as part of the Sudbury Enviromenal Study will lead to more quantiative relationships between smelter emission rates and impact on wet deposition.

In the report published in February, 1979 (1), it was concluded that no statistically significant difference could be found between precipitation concentration and wet deposition of acids measured during the smelter operating and shutdown periods in the summer and autumn of 1978. It was also suggested that most of the acids deposited by precipitation are imported into the region. In that particular analysis, data from the whole area, and unstratified by frontal type or plume sector, were pooled together to arrive at the conclusions. In the present report, data have been stratified according to weather systems and whether or not the samples were affected by the local source. As can be seen from Table 10, the local source contribution to the total wet deposition into an area defined by 50 km amounts to only 9 and 21% for warm and cold fronts respectively. The overall average value, for all types of fronts, would be about 15%. The current findings are thus consistent with the conclusions reported earlier (1). In view of the large variability inherent in precipitation chemistry and wet deposition measurements,

and the relatively small smelter contribution over the network, it is not surprising that the background "noise" inherent in the data of the earlier report masked any differences due to smelter operating conditions.

4. Conclusions

In this report, precipitation data collected in Sudbury during a number of events in August and September, 1978 and from June to October, 1979 were examined to assess the impact of the INCO source on local precipitation quality and to determine the resulting wet deposition pattern. Other atmospheric pathways affecting the fate of the emitted pollutants, such as dry deposition and chemical transformation, are not discussed, and therefore the results reported here should not be taken as the only atmospheric fate of the emitted pollutants. Thirty-one summer/autumn precipitation events were examined, and thus the conclusions are based on a data set which is relatively small, and which will be expanded as more samples are collected and analyzed. In order to properly evaluate the impact of the local source on precipitation quality, it was necessary to consider more than one or two parameters (e.g. free hydrogen ion and sulfate) only. Relatively complex analysis techniques, applied to data collected on a long-term basis, had to be developed. The conclusions reported here result from the development of new data analysis techniques which involved both meteorological stratification and sector analysis.

As the results presented here involved extrapolation of limited summer/autumn data to a yearly basis, some of the conclusions (especially for sulfur and acids) may be revised in the future. Nevertheless, the following conclusions were drawn:

- The quality of precipitation in the Sudbury area is highly dependent on the origin of the air mass associated with the precipitation, and this is reflected in differences in background precipitation chemistry for cold and warm frontal passages. Based on the 31 events selected for discussion in this report, it was found that during warm frontal passages, the most prevalent wind directions were southerly and southwesterly, whereas for the cold frontal cases, the predominant directions were northwesterly and northerly with a smaller southerly component. Parameters such as H_f (free hydrogen ions), H_t (total hydrogen ions), SO_4 , NO_3 , NH_4 , F, Pb and Cd have higher concentrations in warm frontal precipitation, and are probably largely imported into the Sudbury area from the Eastern United States and Southern Ontario.

- A preliminary estimate was made of the relative contributions of local sources and long-range transport to wet deposition in the Sudbury area. The contribution of local sources was generally relatively higher on days of cold frontal precipitation than on days of warm frontal precipitation. Expressing the local contribution as a percentage of the total desposition, the following results were obtained: for cold fronts - S, 31%; Fe, 18%; Cu, 38%; Ni, 38%; Pb, 20%; Zn, 13%; H_f , 21% and for warm fronts - S, 12%; Fe, 11%; Cu, 44%; Ni, 42%; Pb, 10%; Zn, 11%; and H_f , 9%. For acids, the present results are not inconsistent with those of an earlier report (1), where no significant difference could be found in precipitation concentrations or deposition in the Sudbury area during smelter operation and shutdown periods due to the large background contribution and the inherent spatial and temporal variability of these parameters.
- In spite of this large background contribution of many chemical parameters, a careful sector analysis of the data reveals a definite influence of smelting activities on local precipitation quality. Samples within the sector affected by the plume show statistically significant increases (over background samples) of acidity, as well as in concentrations of SO_4 , Fe, Cu, Ni, Pb and Cd. The additional plume sector concentrations generally range from one-half to twice the background values, and, in the case of Cu and Ni, can be an order of magnitude higher than the background values.
- The additional plume sector precipitation concentration for many trace metals falls off approximately exponentially with distance from the source, approaching chemical analysis detection limit values within 100 km of the source. A different relationship is suggested by the data for H_f , SO_4 , and some of the soil-derived parameters, which will have to await a larger data base before it can be clarified.
- The removal of trace metals by precipitation is an efficient process. On days when precipitation occurs, more than 50% of the trace metal emissions can be deposited within 50 km of the source. When compared to annual emissions (taking the precipitation frequency into account) our preliminary estimates for the

percentage of INCO - emitted trace metals that are wet-deposited throughout the year within 50 km are: Fe, 19%; Cu, 17%; Ni, 17%; Pb, 10%; and Zn, 39%.

- The wet-removal of the total emitted sulfur on precipitation days is estimated to be considerably smaller - i.e. about 1% (1.5×10^4 kg/day) . On the other hand, for H_f wet-removal is 79% (5.7×10^2 kg/day) within 50 km of the source. It is speculated that these results are due to the much more efficient wet removal of particulate (largely H_2SO_4) than gaseous (SO_2) sulfur from the plume, and possibly also due to the formation of sulfuric acid within the plume. When prorated over an annual basis, the corresponding percentages removed by wet deposition are: S, 0.3%; and H_f , 26%.

5. Future Work

The emphasis of this report was to examine the effects of INCO's operations on precipitation quality in the Sudbury area. Due to the sparsity of data for Falconbridge, its effects were only estimated qualitatively. Future work will include the following refinements and additional analyses:

- (1) A quantitative evaluation of the impact of Falconbridge, (which will be possible when additional data become available)
- (2) A refinement of the INCO impact analysis.
- (3) Estimates of rain and snow scavenging efficiency, for use in SES mathematical models.
- (4) A comparison of monthly concentrations and depositions as determined by the event and cumulative networks.

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4. "Bulk Deposition in the Sudbury and Muskoka-Haliburton Areas of Ontario During the Shutdown of INCO Ltd. in Sudbury", Water Resources Branch, Ontario Ministry of the Environment, May 1980.

Table 1: Details of Precipitation Sample Analyses

<u>Parameter</u>	<u>Analysis Method</u>	<u>Detection Limit (mg l⁻¹)</u>
pH (for H _f determination)	Radiometer	+ 0.1 pH unit
Total Acidity (for H _f determination)	NaOH titration to pH 8.3; results presented as mg CaCO ₃ l ⁻¹	+ 0.08
SO ₄	Ion Chromatography	+ 0.04 *
N-NO ₃	Ion Chromatography	+ 0.01 *
Cl	Ion Chromatography	+ 0.04 *
F	Ion Chromatography	+ 0.04 *
N-NH ₄	Automated phenate-hypochlorite method	+ 0.008
Ca	Flame atomic absorption	+ 0.02 *
Na	Flame atomic absorption	+ 0.02 *
K	Flame atomic absorption	+ 0.02 *
Mg	Flame atomic absorption	+ 0.02 *
Zn	Flame atomic absorption	+ 0.001
Fe	Flameless atomic absorption	+ 0.001
Ni	Flameless atomic absorption	+ 0.001
Cu	Flameless atomic absorption	+ 0.001
Pb	Flameless atomic absorption	+ 0.001
Al	Flameless atomic absorption	+ 0.005
Cr	Flameless atomic absorption	+ 0.0005
Cd	Flameless atomic absorption	+ 0.0001

* Values correspond to lowest values reported.

Table 2: Data Subsets and Their Associated Criteria for Categorizing

Problem Data

1. The absolute difference between field and laboratory measured pH was greater than or equal to 0.4 pH units.
2. Obvious contamination was noted but sample was submitted.
3. The sampling period was not within 24 ± 6 hours.
4. Contamination of one or more chemical parameters was apparent from chemical analysis results although sample appeared clean.

Accepted Data

1. Clean, clear, properly collected samples with good chemical analysis results.
2. Visual evidence of slight contamination by an insect or particulates but not both. Analytical results appear reasonable.
3. Difference between field and lab pH less than 0.4 pH units. In this case, the lab pH value is generally used, except where the field value is obviously more consistent with other, nearby measurements.

TABLE 3 : MEAN BACKGROUND PRECIPITATION CONCENTRATION (HG/L)

	MEAN BACKGROUND CONCENTRATION (HG/L)						B/A	T-T
	WARM FRONT (A)			COLD FRONT (B)				
	MEAN	STDEV	NN	MEAN	STDEV	NN		
HF	0.0776	0.0227	16.	0.0289	0.0120	14.	0.37	7.19*
PH +	4.1558	0.1477	16.	4.6220	0.2148	14.	1.11	7.00*
ACID	6.6296	1.6722	16.	3.2309	0.7202	12.	0.49	6.57*
SO4	4.8058	1.1713	16.	1.4120	0.5218	14.	0.29	9.99*
NO3	0.6064	0.2335	16.	0.2096	0.1476	14.	0.35	5.47*
NH4	0.6068	0.2681	16.	0.2511	0.1126	13.	0.41	4.46*
CL	0.2045	0.1151	16.	0.1549	0.0824	13.	0.76	1.30
CA	0.4532	0.2212	16.	0.1788	0.0948	14.	0.39	4.30*
HG	0.0668	0.0505	16.	0.0453	0.0439	14.	0.68	1.24
NA	0.0726	0.0379	16.	0.0483	0.0442	14.	0.89	0.53
K	0.1066	0.0928	16.	0.0778	0.0431	14.	0.73	0.98
F	0.0396	0.0132	15.	0.0268	0.0137	13.	0.73	2.12*
FE	0.0391	0.0260	16.	0.0223	0.0133	14.	0.57	2.18*
CU	0.0031	0.0019	16.	0.0040	0.0027	14.	1.29	-1.07
NI	0.0014	0.0003	16.	0.0016	0.0006	14.	1.14	-1.16
PR	0.0124	0.0046	16.	0.0055	0.0032	14.	0.64	4.70*
ZN	0.0154	0.0066	16.	0.0125	0.0076	14.	0.81	2.12
AL	0.0280	0.0195	16.	0.0137	0.0098	14.	0.49	2.48*
CR	0.0006	0.0002	16.	0.0008	0.0004	14.	1.33	-1.77
CD	0.0002	0.0001	16.	0.0001	0.0001	14.	0.50	2.73

† : IN PH UNITS

MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS

STDEV : STANDARD DEVIATION

NN : NUMBER OF DATA POINTS (EVENTS)

T-T : STUDENT-T STATISTICS

* : STATISTICALLY SIGNIFICANT AT 95 % CONFIDENCE LEVEL

TABLE 4 : RELATIVE BACKGROUND AND PLUME CONCENTRATIONS ASSOCIATED WITH WARM FRONTAL PASSAGE.

	CONCENTRATION (MG/L)						ADDITIONAL (C)					
	BACKGROUND (A)			PLUME (B)			MEAN			STDV		
	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN
HF	0.0776	0.0227	16.	0.0971	0.0475	13.	0.0284	0.0324	13.	1.25	-1.45	0.37
PH	4.1558	0.1477	16.	4.0715	0.2180	13.	0.0432	0.0749	13.	0.98	1.24	0.01
ACID	6.6296	1.6722	16.	8.5580	2.9024	11.	1.9248	2.0380	11.	1.29	-2.19*	0.29
SO4	4.8058	1.1713	16.	7.7511	2.2381	14.	2.8667	1.8279	14.	1.61	-4.60*	0.60
NO3	0.6064	0.2335	16.	0.7928	0.3489	13.	0.2108	0.2438	13.	1.31	-1.72	0.35
NH4	0.6068	0.2681	16.	0.8077	0.3745	13.	0.1976	0.3149	13.	1.33	-1.68	0.33
CL	0.2045	0.1151	16.	0.1832	0.0648	13.	0.0305	0.0460	13.	0.90	0.59	0.15
CA	0.4532	0.2212	16.	0.5841	0.4838	12.	0.1714	0.2416	12.	1.29	-0.96	0.38
MG	0.0668	0.0505	16.	0.0724	0.0545	12.	0.0221	0.0285	12.	1.08	-0.28	0.33
NA	0.0726	0.0379	16.	0.0930	0.0640	12.	0.0328	0.0453	12.	1.28	-1.06	0.43
K	0.1066	0.0928	16.	0.0926	0.0818	13.	0.0210	0.0295	13.	0.87	0.43	0.20
F	0.0396	0.0132	15.	0.0415	0.0212	13.	0.0090	0.0123	13.	1.05	-0.29	0.23
FE	0.0391	0.0260	16.	0.0808	0.0479	14.	0.0405	0.0294	14.	2.07	-3.02*	1.04
CU	0.0031	0.0019	16.	0.0281	0.0236	14.	0.0248	0.0237	14.	9.06	-4.23*	8.00
NI	0.0014	0.0003	16.	0.0141	0.0147	14.	0.0128	0.0146	14.	10.07	-3.46*	9.14
PB	0.0124	0.0046	16.	0.0206	0.0081	14.	0.0080	0.0064	14.	1.66	-3.47*	0.65
ZN	0.0154	0.0066	16.	0.0181	0.0074	14.	0.0070	0.0075	14.	1.18	-1.06	0.45
AL	0.0280	0.0195	16.	0.0450	0.0355	14.	0.0200	0.0250	14.	1.61	-1.65	0.71
CR	0.0006	0.0002	16.	0.0006	0.0003	13.	0.0001	0.0003	13.	1.00	0.0	0.17
CD	0.0002	0.0001	16.	0.0004	0.0002	14.	0.0002	0.0002	14.	2.00	-3.53*	1.00

† : IN PH UNITS
 MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS
 STDV : STANDARD DEVIATION
 NN : NUMBER OF DATA POINTS (EVENTS)
 T-T : STUDENT-T STATISTICS
 * : STATISTICALLY SIGNIFICANT AT 95 % CONFIDENCE LEVEL

TABLE 5 : RELATIVE BACKGROUND AND PLUME CONCENTRATIONS ASSOCIATED WITH COLD FRONTAL PASSAGE.

	CONCENTRATION (MG/L)						ADDITIONAL (C)						B/A	T-T	C/A
	BACKGROUND (A)			PLUME (B)			MEAN			STDV					
	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN			
HF +	0.0289	0.0120	14.	0.0575	0.0311	15.	0.0272	0.0262	14.	0.0272	0.0262	14.	1.99	-3.22*	0.94
PH +	4.6220	0.2148	14.	4.3235	0.2268	15.	0.0261	0.0481	14.	0.0261	0.0481	14.	0.94	3.63*	0.01
ACID	3.2309	0.7202	12.	4.8403	1.6983	13.	1.6038	1.3946	12.	1.6038	1.3946	12.	1.50	-3.04*	0.50
SO4	1.4120	0.5218	14.	3.2173	1.1189	15.	1.7734	1.1053	14.	1.7734	1.1053	14.	2.28	-5.50*	1.26
NO3	0.2096	0.1476	14.	0.2726	0.1566	15.	0.0778	0.0929	14.	0.0778	0.0929	14.	1.30	-1.11	0.37
NH4	0.2511	0.1126	13.	0.3225	0.1871	15.	0.1152	0.1130	13.	0.1152	0.1130	13.	1.28	-1.20	0.44
CL	0.1549	0.0824	13.	0.1363	0.0653	14.	0.0339	0.0443	13.	0.0339	0.0443	13.	0.88	0.65	0.22
CA	0.1788	0.0948	14.	0.2011	0.1060	15.	0.0529	0.0596	14.	0.0529	0.0596	14.	1.12	-0.60	0.30
HG	0.0453	0.0439	14.	0.0412	0.0294	15.	0.0153	0.0231	14.	0.0153	0.0231	14.	0.91	0.30	0.34
NA	0.0446	0.0442	14.	0.0802	0.0959	15.	0.0355	0.0749	14.	0.0355	0.0749	14.	1.24	-0.56	0.55
K	0.0778	0.0621	14.	0.0747	0.0625	15.	0.0371	0.0562	14.	0.0371	0.0562	14.	0.96	0.13	0.48
F	0.0288	0.0137	13.	0.0312	0.0130	13.	0.0043	0.0059	12.	0.0043	0.0059	12.	1.08	-0.46	0.15
FE	0.0223	0.0133	14.	0.0499	0.0344	15.	0.0321	0.0355	14.	0.0321	0.0355	14.	2.24	-2.81*	1.44
CU	0.0040	0.0027	14.	0.0280	0.0237	15.	0.0251	0.0239	14.	0.0251	0.0239	14.	7.00	-3.76*	6.27
NI	0.0016	0.0006	14.	0.0151	0.0132	15.	0.0143	0.0131	14.	0.0143	0.0131	14.	9.44	-3.82*	8.94
PB	0.0055	0.0032	14.	0.0109	0.0064	15.	0.0054	0.0056	14.	0.0054	0.0056	14.	1.98	-2.84*	0.98
ZN	0.0125	0.0076	14.	0.0152	0.0105	15.	0.0075	0.0079	14.	0.0075	0.0079	14.	1.22	-0.79	0.60
AL	0.0137	0.0098	14.	0.0164	0.0110	15.	0.0075	0.0105	14.	0.0075	0.0105	14.	1.20	-0.70	0.55
CR	0.0008	0.0004	14.	0.0008	0.0006	15.	0.0002	0.0004	14.	0.0002	0.0004	14.	1.00	0.0	0.75
CD	0.0001	0.0001	14.	0.0004	0.0003	15.	0.0002	0.0003	14.	0.0002	0.0003	14.	1.00	-3.56*	2.00

* : IN PH UNITS

MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS

STDV : STANDARD DEVIATION

NN : NUMBER OF DATA POINTS (EVENTS)

T-T : STUDENT-T STATISTICS

* : STATISTICALLY SIGNIFICANT AT 95 % CONFIDENCE LEVEL

TABLE 6 : ADDITIONAL CONCENTRATION (MG/L)

--- DUE TO PLUME-PRECIPIATION INTERACTION ---

	WARM(A)		COLD(B)		B/A	T-T
	MEAN	STDV	MEAN	STDV		
HF	0.0284	0.0324	0.0272	0.0262	0.96	0.11
PH +	0.0432	0.0749	0.0261	0.0481	0.60	0.71
ACID	1.9248	2.0380	1.7038	1.3946	0.83	0.44
SO4	2.8667	1.8279	1.7734	1.1053	0.62	1.92
NO3	0.2108	0.2438	0.0778	0.0929	0.37	1.90
NH4	0.1976	0.3149	0.1152	0.1130	0.58	0.89
CL	0.0305	0.0460	0.0339	0.0443	1.11	-0.19
CA	0.1714	0.2416	0.0329	0.0596	0.31	1.78
MG	0.0221	0.0285	0.0353	0.0231	0.69	0.67
NA	0.0328	0.0453	0.0335	0.0749	1.08	-0.11
K	0.0210	0.0295	0.0331	0.0562	1.77	-0.92
F	0.0090	0.0123	0.0043	0.0059	0.48	1.20
FE	0.0405	0.0294	0.0321	0.0355	0.79	0.68
CU	0.0248	0.0237	0.0251	0.0239	1.01	-0.03
NI	0.0128	0.0146	0.0143	0.0131	1.12	-0.29
PB	0.0080	0.0064	0.0054	0.0056	0.67	1.14
ZN	0.0070	0.0075	0.0075	0.0079	1.07	-0.17
AL	0.0200	0.0250	0.0075	0.0105	0.38	1.72
CR	0.0001	0.0003	0.0002	0.0004	2.00	-0.73
CD	0.0002	0.0002	0.0002	0.0003	1.00	0.0

+ : IN PH UNITS
 MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS
 STDV : STANDARD DEVIATION
 NN : NUMBER OF DATA POINTS (EVENTS)
 T-T : STUDENT-T STATISTICS

TABLE 2 - RC MEAN ADDITIONAL CONCENTRATION(MG/L) & STANDARD DEVIATION DUE TO PLUME CONTRIBUTION.

	(3.- 6.) KM			(9.-11.) KM			(14.-18.) KM			(21.-27.) KM			(31.-32.) KM		
	NN	CONC	STDU	NN	CONC	STDU	NN	CONC	STDU	NN	CONC	STDU	NN	CONC	STDU
HF	28	0.0331	0.0409	19	0.0231	0.0261	10	0.0230	0.0176	17	0.0243	0.0317	19	0.0294	0.0271
ACID	23	1.8960	1.9732	16	1.8300	1.7562	10	2.0571	2.7993	13	1.8432	1.9003	16	1.9154	2.0476
SUR	28	2.3505	1.8931	18	1.7298	1.2346	10	2.2816	1.8629	19	2.0782	1.7368	19	2.0066	1.7889
NO3	27	0.1326	0.2178	18	0.0831	0.0999	9	0.2121	0.2868	17	0.1732	0.2488	18	0.1799	0.2261
NH4	26	0.2359	0.3780	17	0.1030	0.1195	10	0.2173	0.1951	16	0.1492	0.2828	16	0.1583	0.2366
CL	26	0.0247	0.0827	17	0.0062	0.0145	10	0.0613	0.0713	17	0.0545	0.1111	18	0.0346	0.0652
CA	25	0.0519	0.0965	18	0.0247	0.0410	7	0.1895	0.2754	13	0.1040	0.2118	16	0.1485	0.2716
NA	27	0.0190	0.0294	18	0.0072	0.0231	8	0.0164	0.0308	16	0.0194	0.0353	14	0.0109	0.0217
MG	26	0.0288	0.0686	17	0.0075	0.0167	10	0.0383	0.0389	14	0.0237	0.0469	15	0.0259	0.0459
K	24	0.0029	0.0084	18	0.0510	0.1043	10	0.0690	0.0926	14	0.0245	0.0536	15	0.0156	0.0327
FE	23	0.0108	0.0207	17	0.0053	0.0269	9	0.0049	0.0133	15	0.0659	0.0093	16	0.0065	0.0120
CU	27	0.0734	0.0710	19	0.0341	0.0478	9	0.0548	0.0653	17	0.0184	0.0253	16	0.0150	0.0178
NI	27	0.0775	0.0838	20	0.0243	0.0223	9	0.0212	0.0170	18	0.0177	0.0107	17	0.0039	0.0047
PB	26	0.0143	0.0171	19	0.0129	0.0111	9	0.0106	0.0143	18	0.0070	0.0073	17	0.0012	0.0024
ZN	26	0.0066	0.0078	19	0.0109	0.0170	9	0.0088	0.0173	17	0.0060	0.0096	16	0.0046	0.0056
CL	26	0.0164	0.0314	19	0.0090	0.0166	9	0.0083	0.0169	17	0.0083	0.0096	16	0.0062	0.0143
CR	26	0.0084	0.0010	18	0.0002	0.0006	9	0.0142	0.0285	17	0.0085	0.0096	16	0.0139	0.0218
CD	25	0.0006	0.0008	19	0.0002	0.0002	9	0.0001	0.0002	17	0.0000	0.0001	14	0.0000	0.0001
										17	0.0003	0.0003	16	0.0001	0.0001

NN : NUMBER OF DATA POINTS (EVENTS)
 CONC : MEAN CONCENTRATION
 STDU : STANDARD DEVIATION

TABLE B : CORRELATION AND REGRESSION COEFFICIENTS FOR
MEAN ADDITIONAL CONCENTRATION AND DISTANCE.

	DTL	LINEAR		LOG		LINEAR		LOG	
		COR1	DIS1	COR2	DIS2	AAA1	BBB1	AAA2	BBB2
HF	0.0025	-0.14	410.	-0.11	1487.	0.02762	-0.00004	-1.56810	-0.00070
ACID	0.0800	0.05	-4213.	0.06	-13305.	1.90094	0.00043	0.27850	0.00010
SO4	0.0400	-0.21	443.	-0.16	2149.	2.17142	-0.00479	0.33127	-0.00080
NO3	0.0100	0.55	-41	0.55	-128.	0.11337	0.00252	-0.96505	0.00811
NH4	0.0080	-0.26	152.	-0.13	768.	0.19832	-0.00125	-0.73948	-0.00177
CL	0.0400	0.45	2.	0.48	26.	0.02027	0.00093	-1.85652	0.01778
CA	0.0200	0.61	-8.	0.66	-11.	0.03801	0.00383	-1.46483	0.02213
MG	0.0200	-0.11	-8.	-0.03	-276.	0.01551	-0.00005	-1.85438	-0.00056
NA	0.0200	0.18	-6.	0.27	13.	0.02111	0.00018	-1.78332	0.00665
K	0.0200	-0.08	77.	0.26	16.	0.03621	-0.00021	-1.90654	0.01308
FE	0.0400	-0.47	-301.	-0.40	-140.	0.00846	-0.00010	-2.10785	-0.00505
CU	0.0010	-0.85	37.	-0.89	80.	0.07251	-0.00193	-1.06400	-0.02420
NI	0.0010	-0.83	30.	-0.95	48.	0.06633	-0.00220	-1.01892	-0.04108
PB	0.0010	-0.86	29.	-0.95	37.	0.03341	-0.00113	-1.24700	-0.04775
ZN	0.0010	-0.69	43.	-0.68	82.	0.01258	-0.00027	-1.91159	-0.01331
AL	0.0020	-0.47	82.	-0.48	137.	0.00928	-0.00009	-2.03873	-0.00481
CR	0.0050	-0.23	118.	-0.19	189.	0.01366	-0.00007	-1.88112	-0.00221
CD	0.0005	-0.89	-6.	-0.97	3.	0.00041	-0.00001	-3.16053	-0.05707
	0.0001	-0.70	30.	-0.75	31.	0.00051	-0.00001	-3.24543	-0.02454

DTL : DETECTION LIMIT (MG/L) EXCEPT FOR HF WHICH IS EQUIVALENT
TO THAT OF "CLEAN PRECIPITATION" (PH=5.6).
COR : CORRELATION COEFFICIENT
DIS : DISTANCE AT WHICH CONCENTRATION EQUALS TO DETECTION LIMIT (KM)
AAA : REGRESSION COEFFICIENT "A".
BBB : REGRESSION COEFFICIENT "B".

Table 9: Estimated Wet Deposition, Emission Rates and % of INCO 381 m Stack Emissions Removed at 50 km.

<u>Parameter</u>	<u>*Wet Deposition (kg/day)</u>	<u>Emission Rate⁺ (kg/day)</u>	<u>Std. Dev. in Emission Rate</u>	<u>Average % Emissions Removed out to 50 km on days when it was raining</u>
S	1.5×10^4	1.7×10^6	n.a.	0.9
Fe	3.5×10^2	6.1×10^2 (10)	5.6×10^2	57
Cu	1.7×10^2	3.3×10^2 (16)	2.8×10^2	52
Ni	7.1×10^1	13.7×10^1 (14)	12.4×10^1	52
Pb	1.0×10^2	3.2×10^2 (3)	0.94×10^2	31
Zn	1.3×10^2	1.1×10^2 (12)	1.1×10^2	118
H _f ^{**}	5.7×10^2	7.2×10^2 (29)	4.0×10^2	79

* Precipitation days only.

** Estimated by assuming that all of the particulate sulfur emitted is in the form of H₂SO₄.

† Values in brackets correspond to the number of particulate-to-SO₂ data points used in calculations.

Table 10: Contribution of INCO Emissions to Total Wet
Deposition in the Sudbury Area (r=50 km)

<u>Parameter</u>	<u>Local Sources Deposition (kg/Day)</u>	<u>Background Deposition (kg/Day)</u>		<u>% Relative Deposition (Local/Total)*</u>	
		<u>Warm Front</u>	<u>Cold Front</u>	<u>Warm Front</u>	<u>Cold Front</u>
S	1.5×10^4	11×10^4	3.3×10^4	12	31
Fe	3.5×10^2	28×10^2	16×10^2	11	18
Cu	1.7×10^2	2.2×10^2	2.8×10^2	44	38
Ni	7.1×10^1	9.7×10^1	11.7×10^1	42	38
Pb	1.0×10^2	8.9×10^2	3.9×10^2	10	20
Zn	1.3×10^2	11×10^2	8.9×10^2	11	13
H _f	5.7×10^2	55×10^2	21×10^2	9	21

* Total wet deposition represents the summation of local plus background deposition.

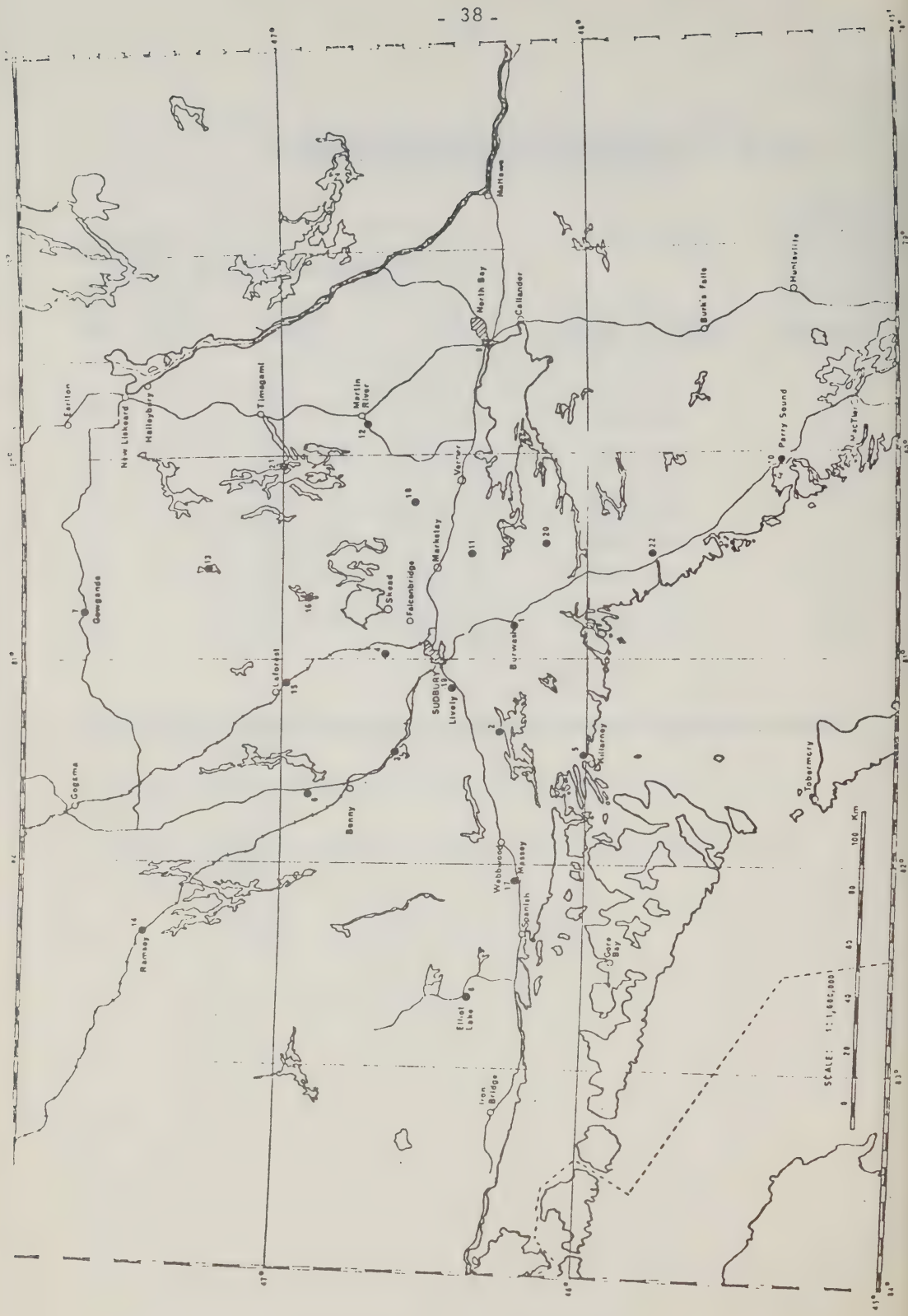
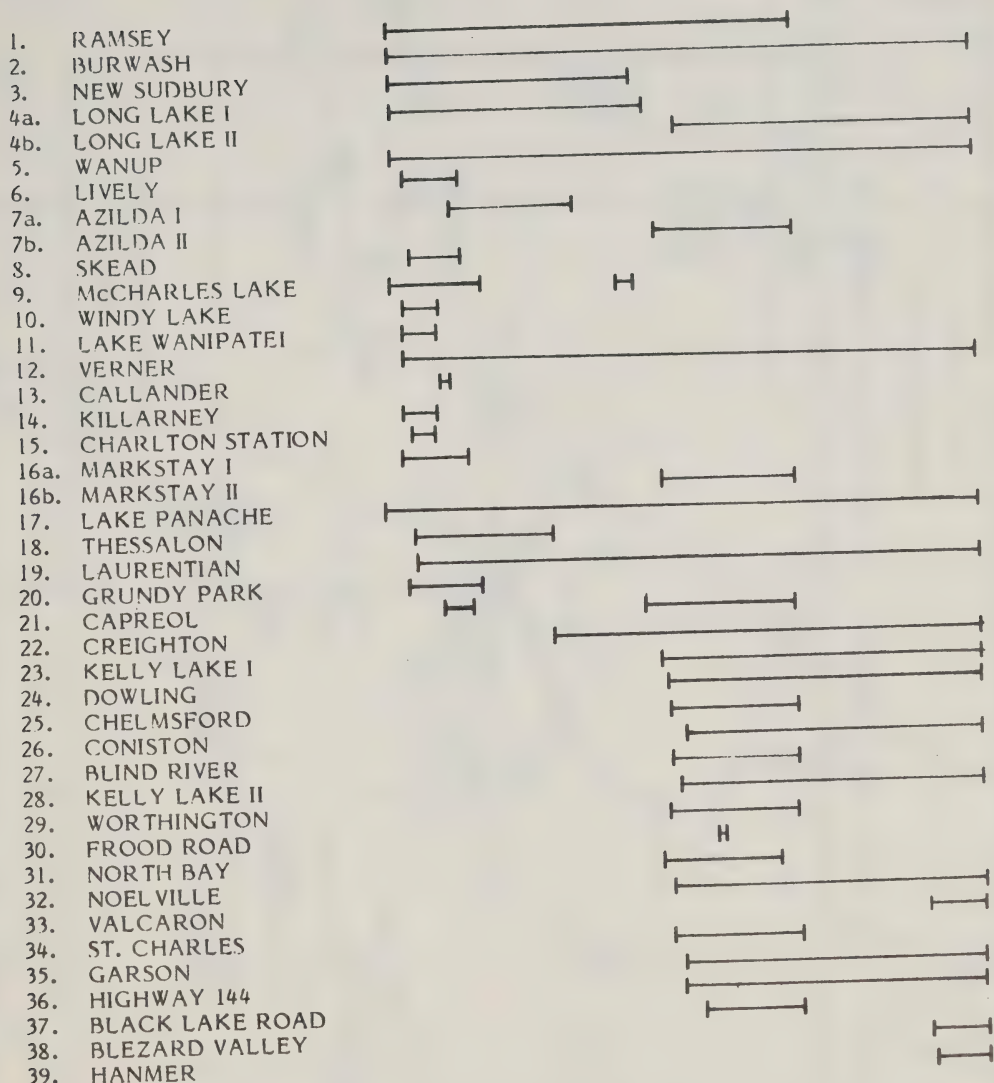
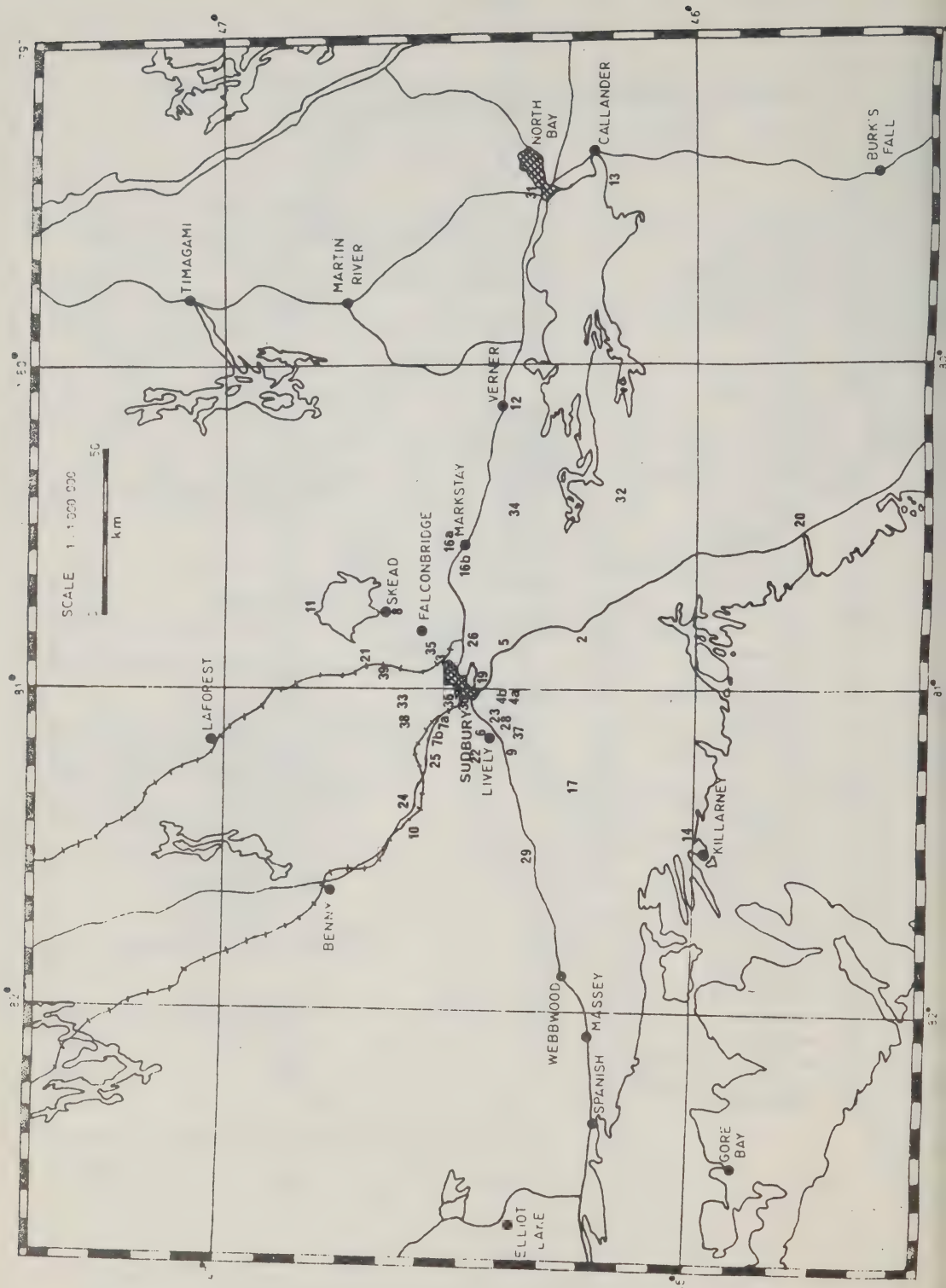


FIGURE 2: A SUMMARY OF SES EVENT PRECIPITATION SAMPLER
OPERATING PERIODS



J J A S O N D J F M A M J J A S O N D J F M A M
1978 1979 1980



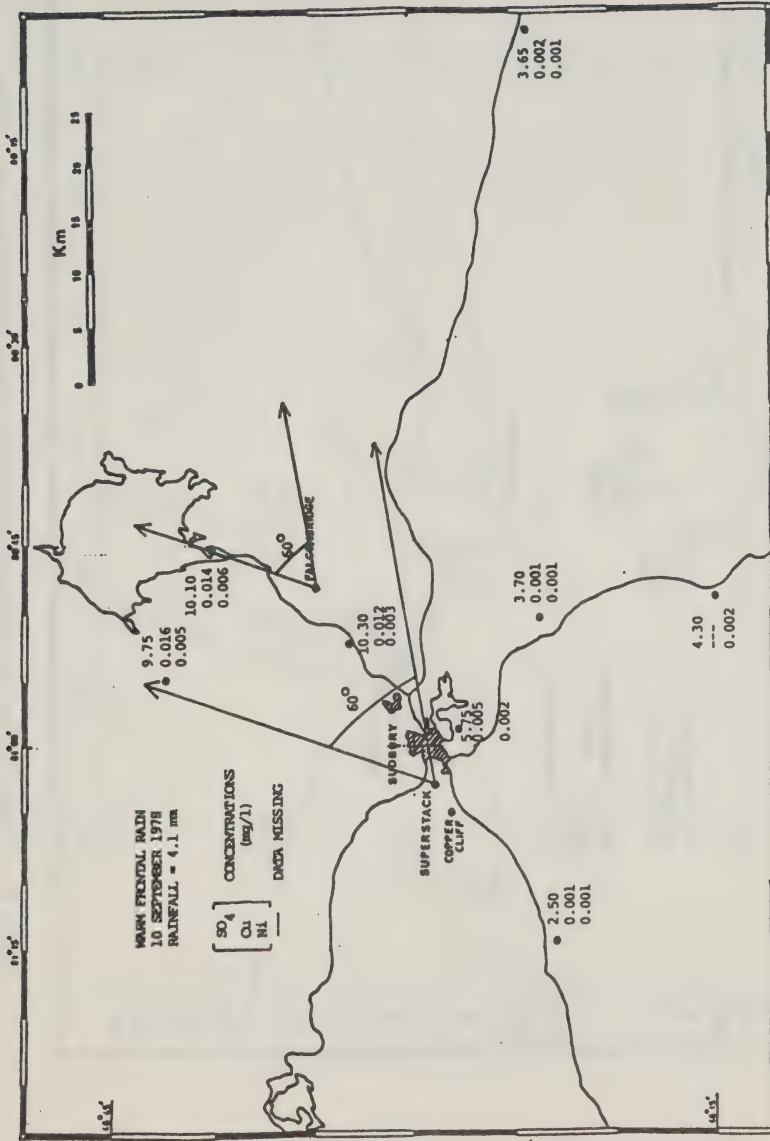


Figure 4: Plume Sector for Warm Frontal Rain Event of 10th September, 1978

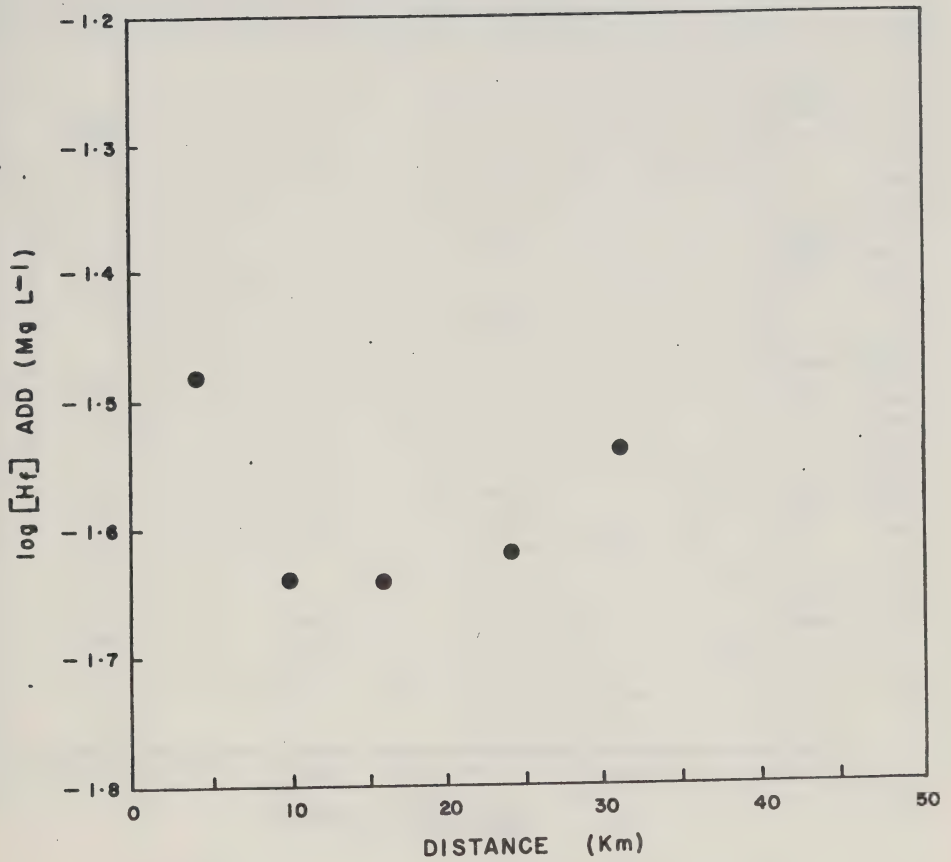


Figure 6: Dependence of Additional H_f Concentration on Distance from INCO Source

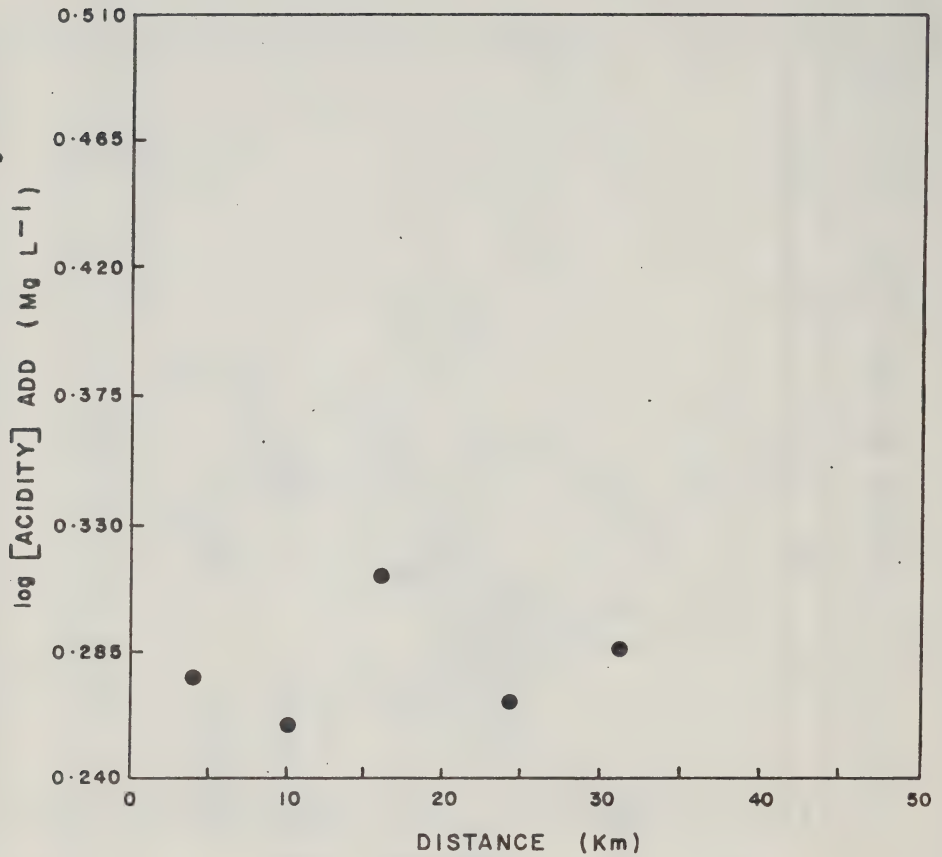


Figure 7: Dependence of Additional Acidity Concentration (expressed as mg CaCO₃/l) on Distance from INCO Source

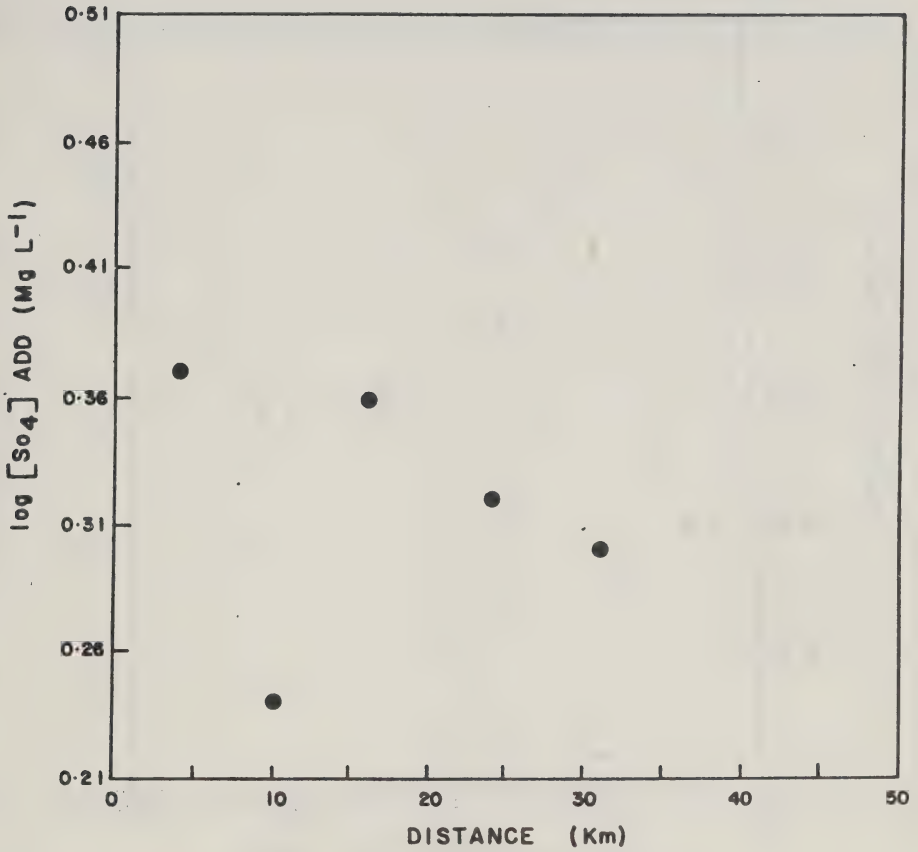


Figure 8: Dependence of Additional SO_4 Concentration on Distance from INCO Source

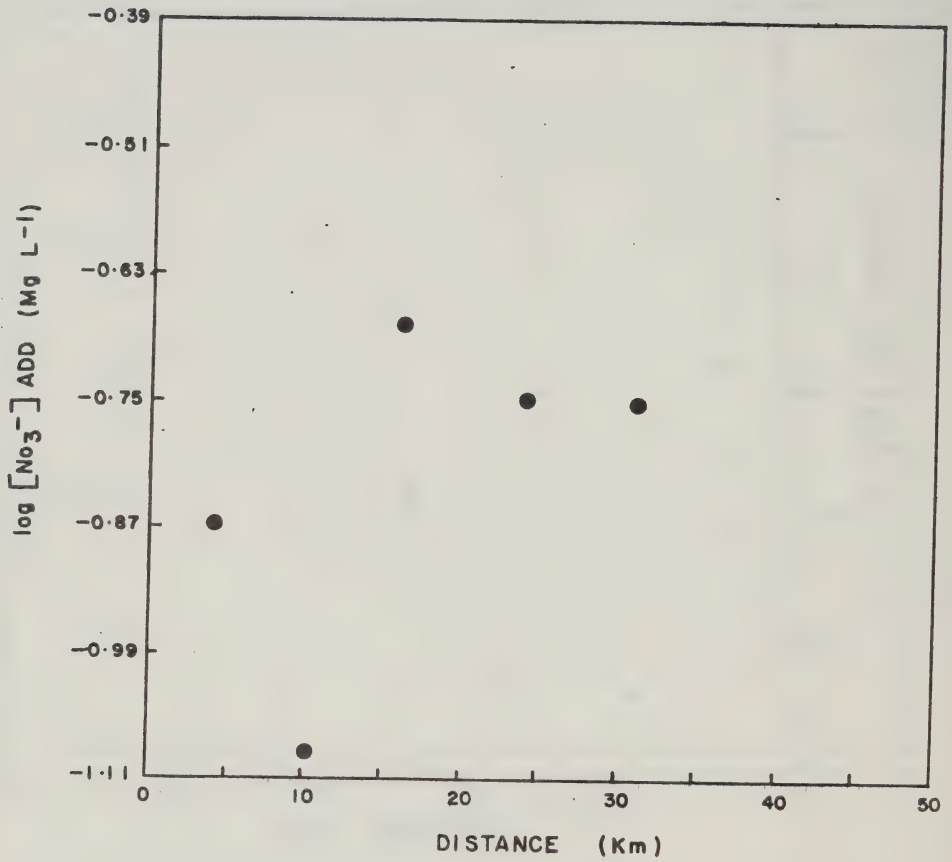


Figure 9: Dependence of Additional NO_3 Concentration on Distance from INCO Source

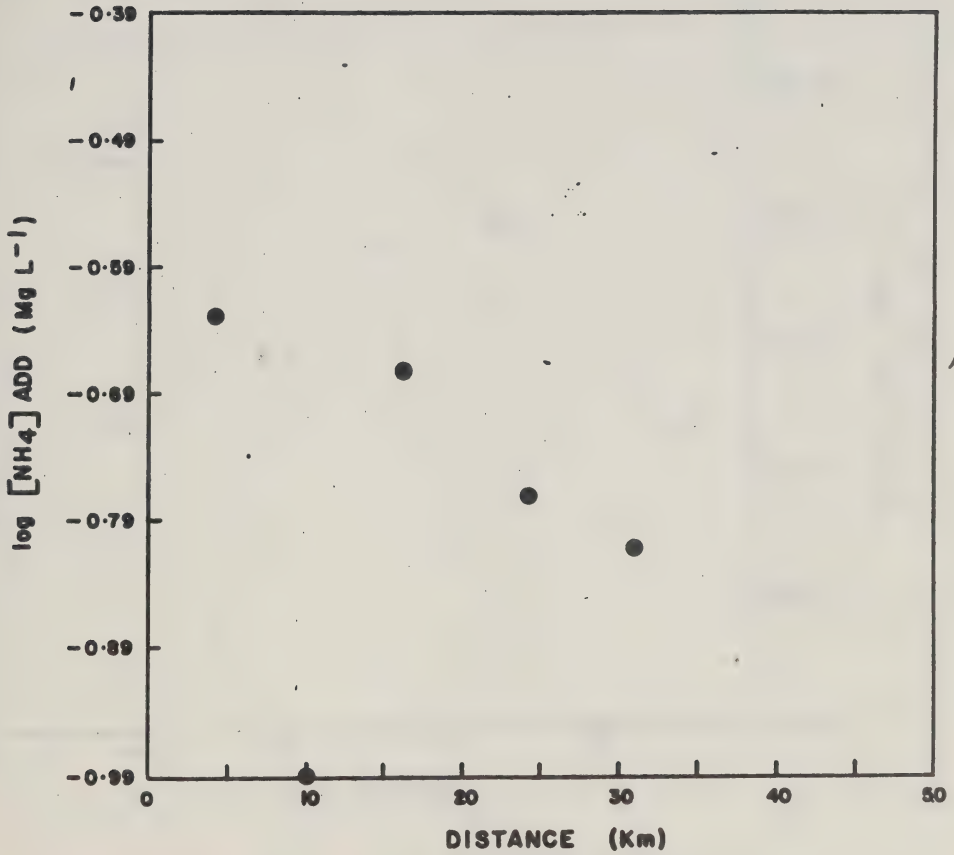


Figure 10: Dependence of Additional NH₄ Concentration on Distance from INCO Source

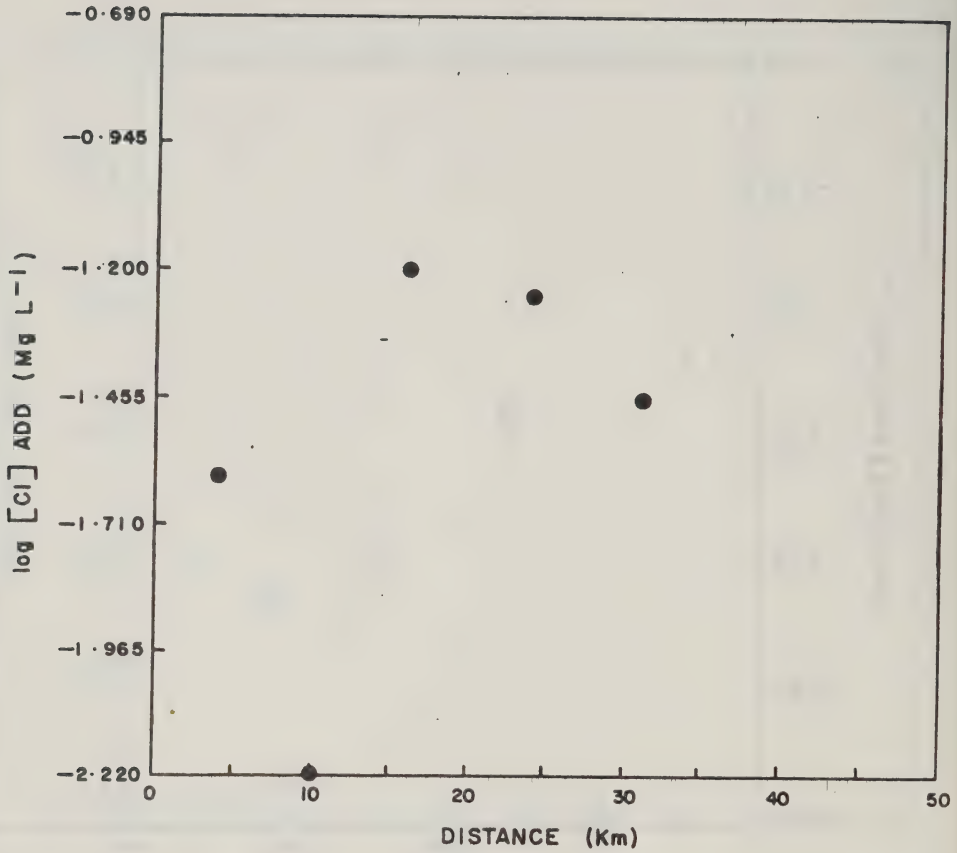


Figure 11: Dependence of Additional Cl Concentration on Distance from INCO Source

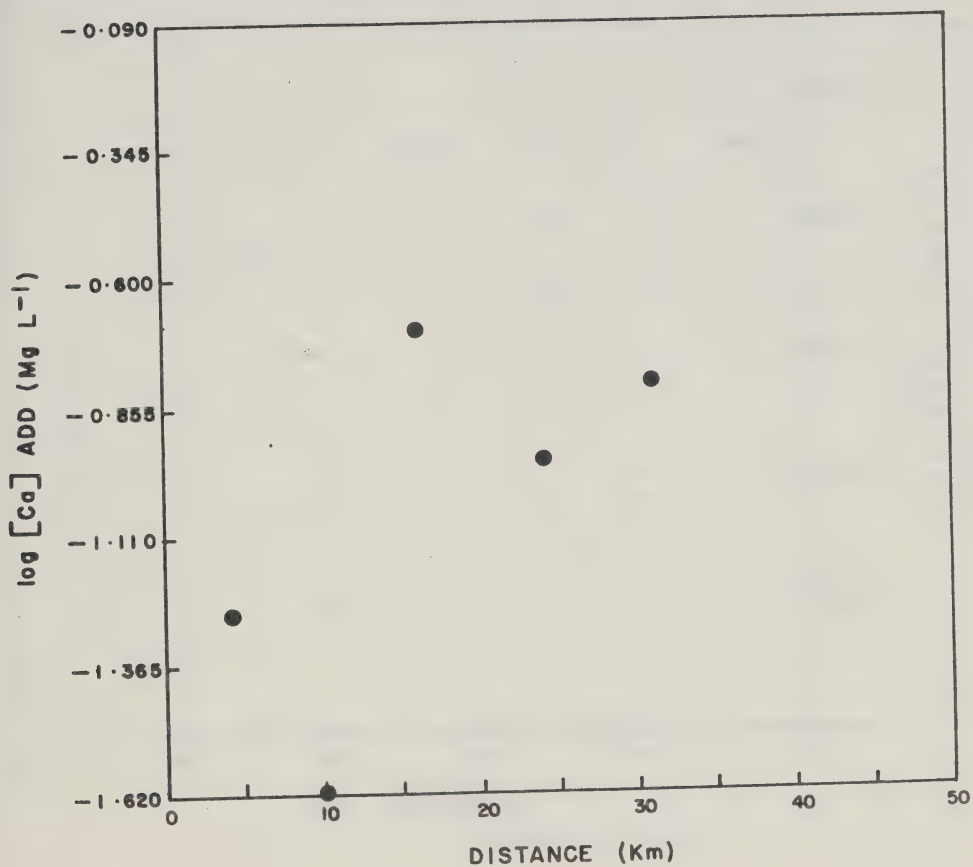


Figure 12: Dependence of Additional Ca Concentration on Distance from INCO Source

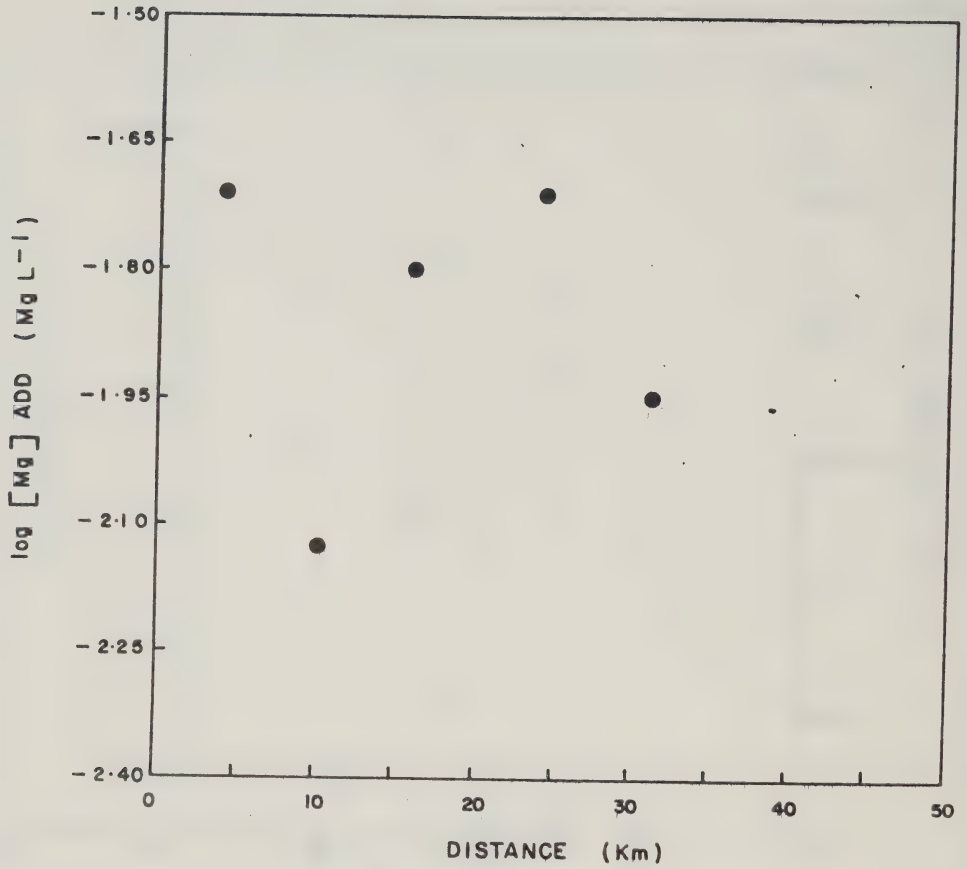


Figure 13: Dependence of Additional Mg Concentration on Distance from INCO Source

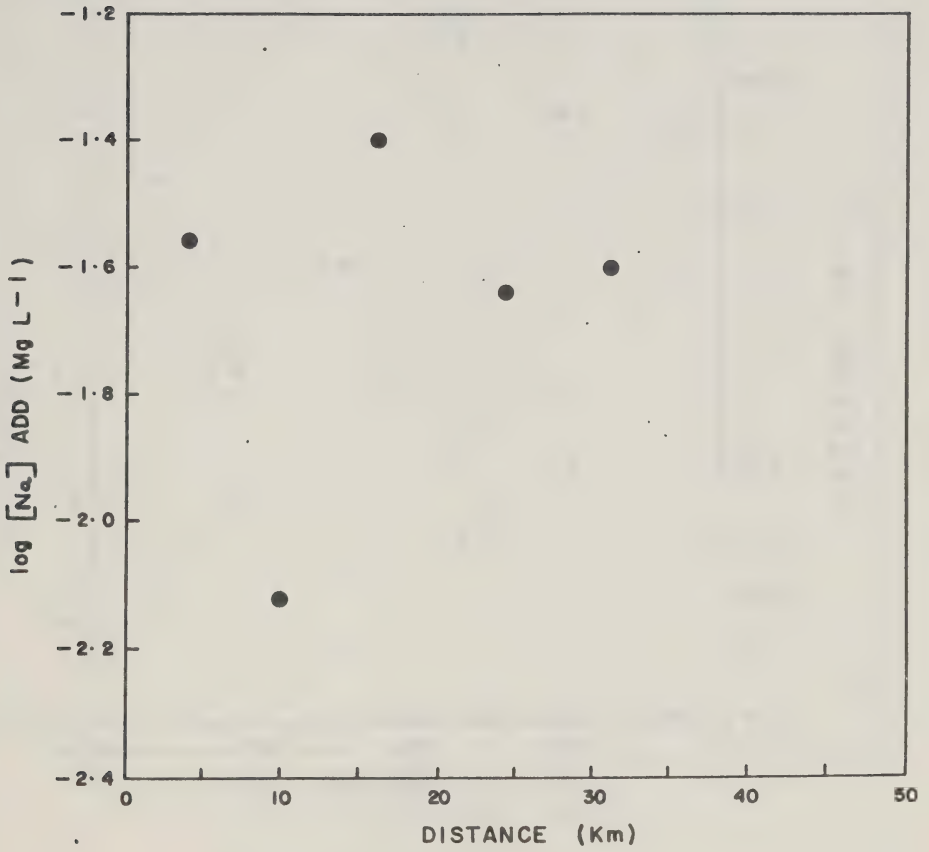


Figure 14: Dependence of Additional Na Concentration on Distance from INCO Source

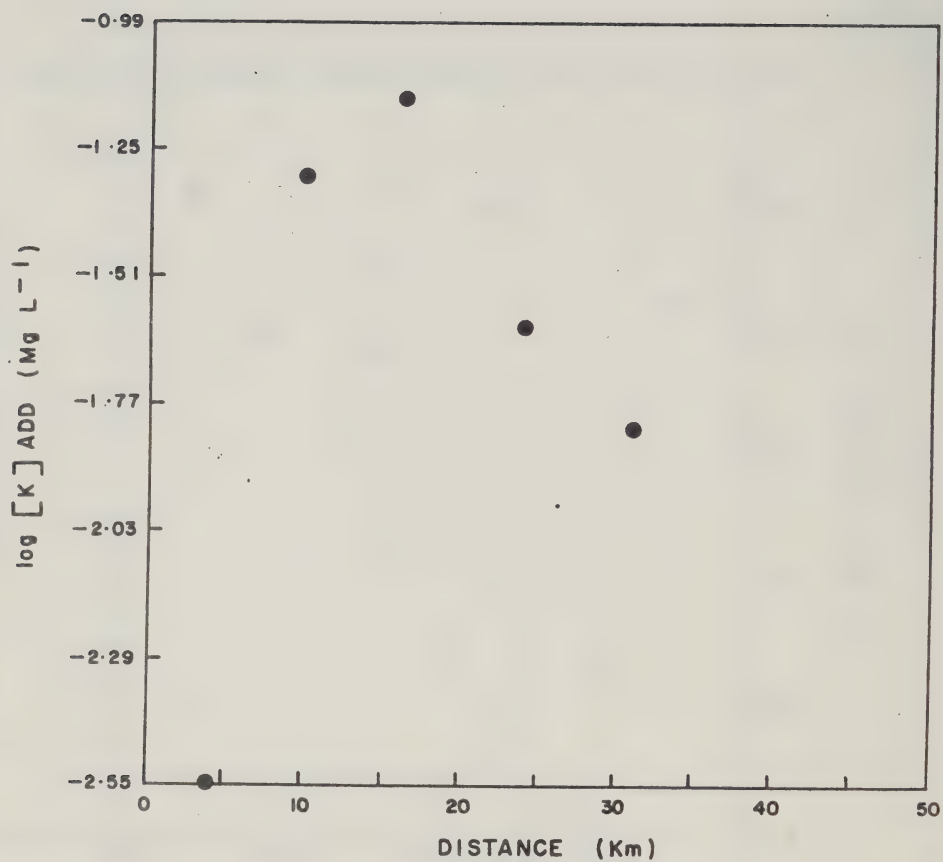


Figure 15: Dependence of Additional K Concentration on Distance from INCO Source

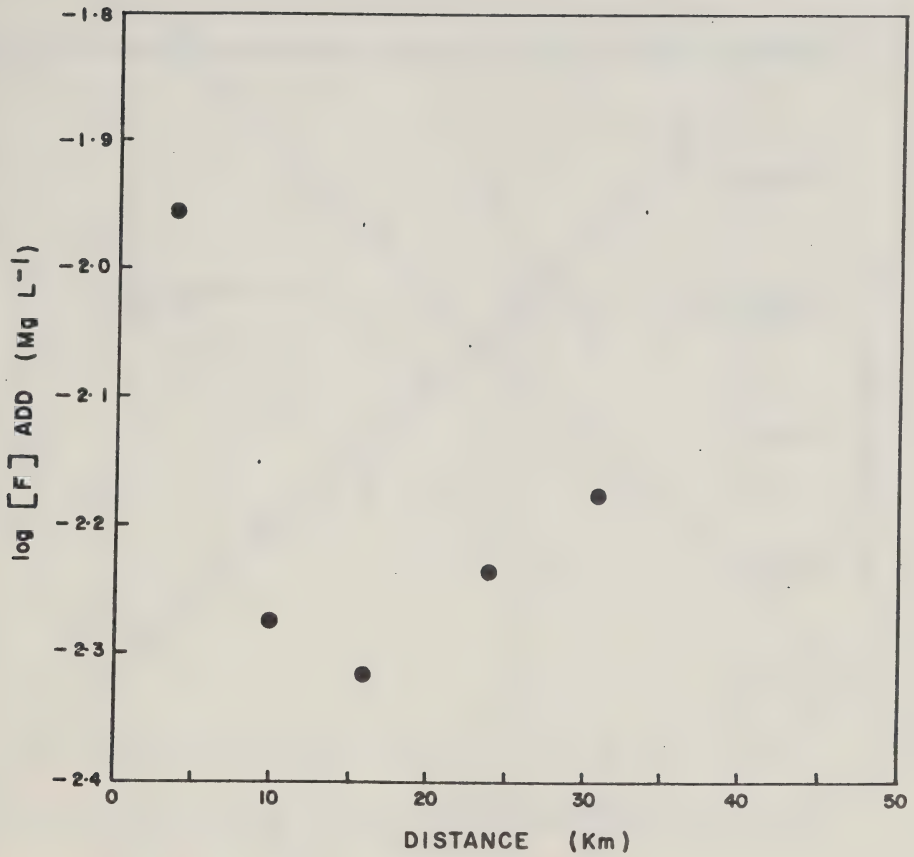


Figure 16: Dependence of Additional F Concentration
on Distance from INCO Source

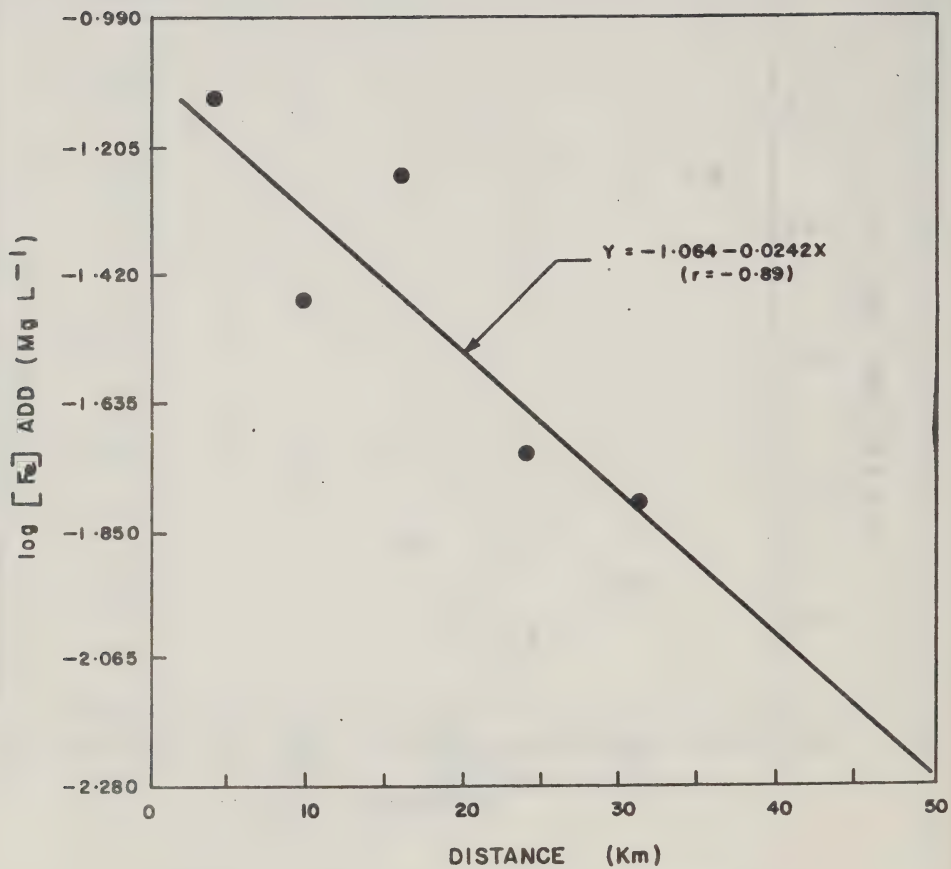


Figure 17: Dependence of Additional Fe Concentration on Distance from INCO Source

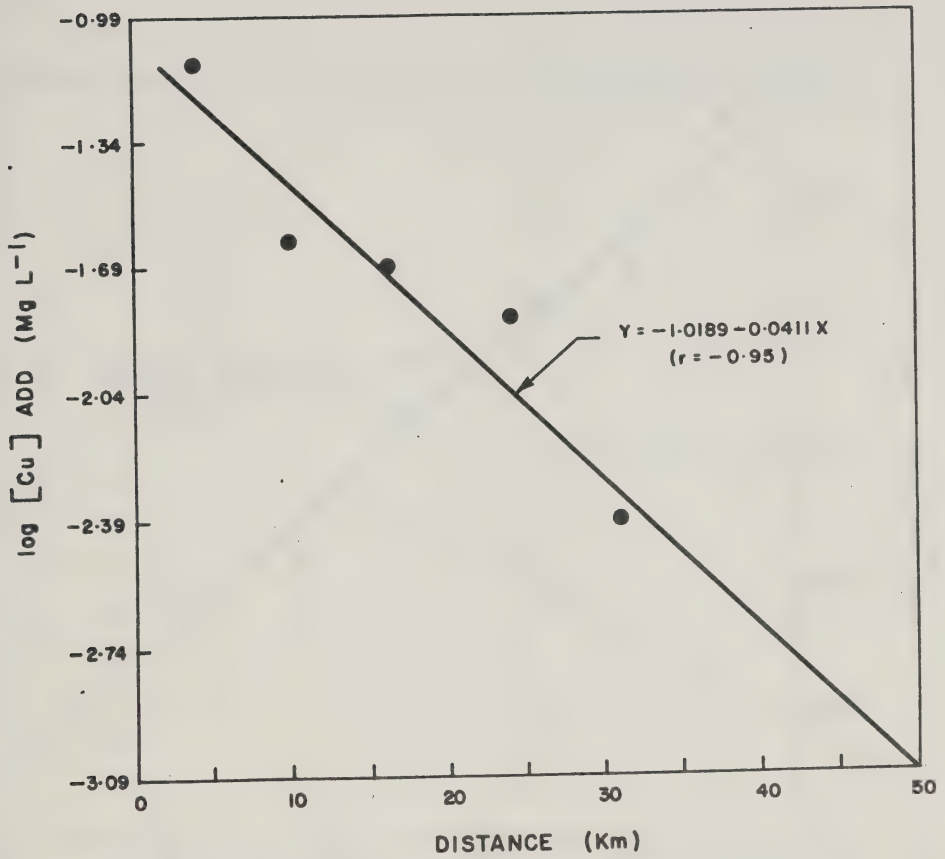


Figure 18: Dependence of Additional Cu Concentration on Distance from INCO Source

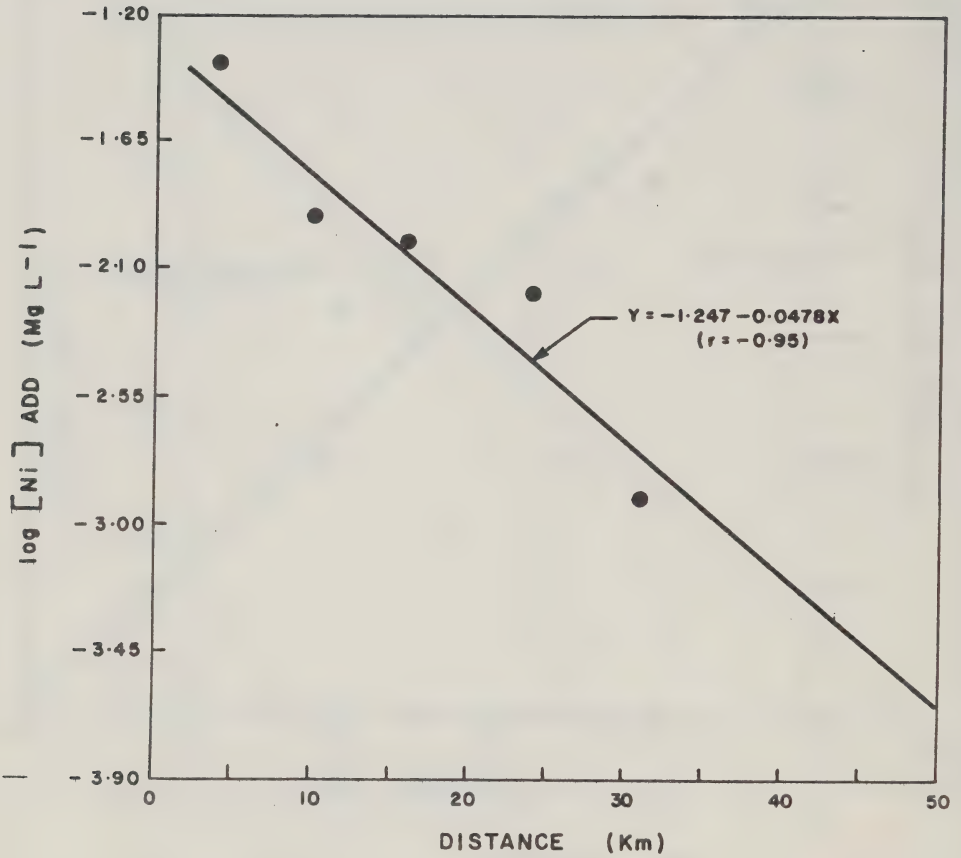


Figure 19: Dependence of Additional Ni Concentration on Distance from INCO Source

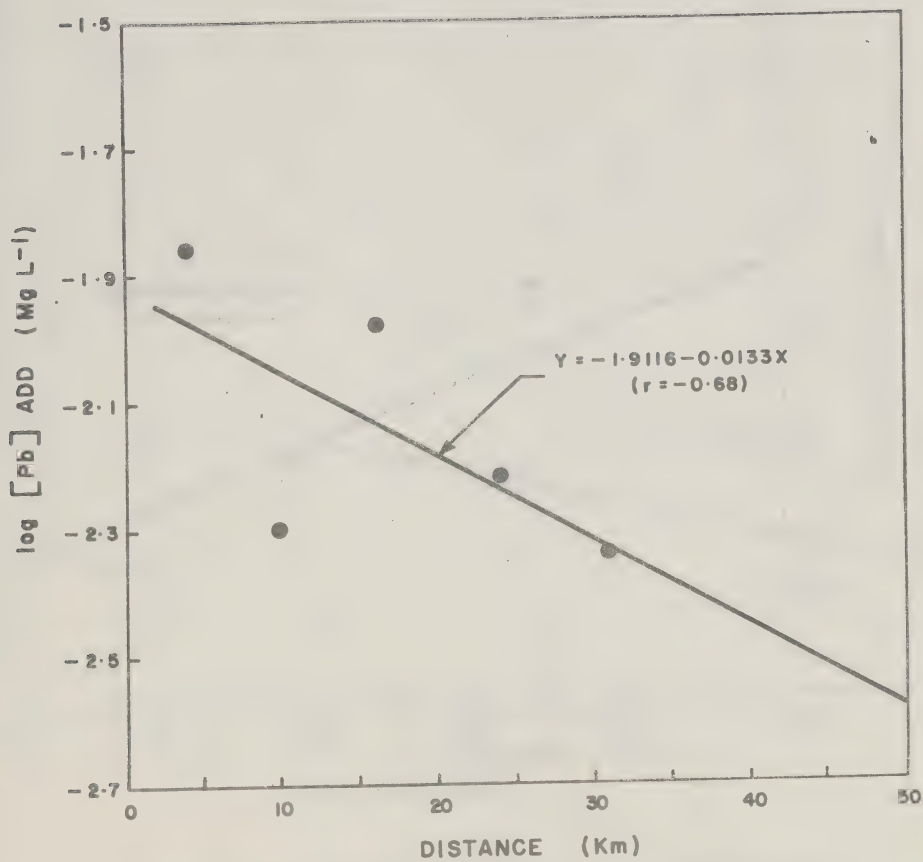


Figure 20: Dependence of Additional Pb Concentration on Distance from INCO Source

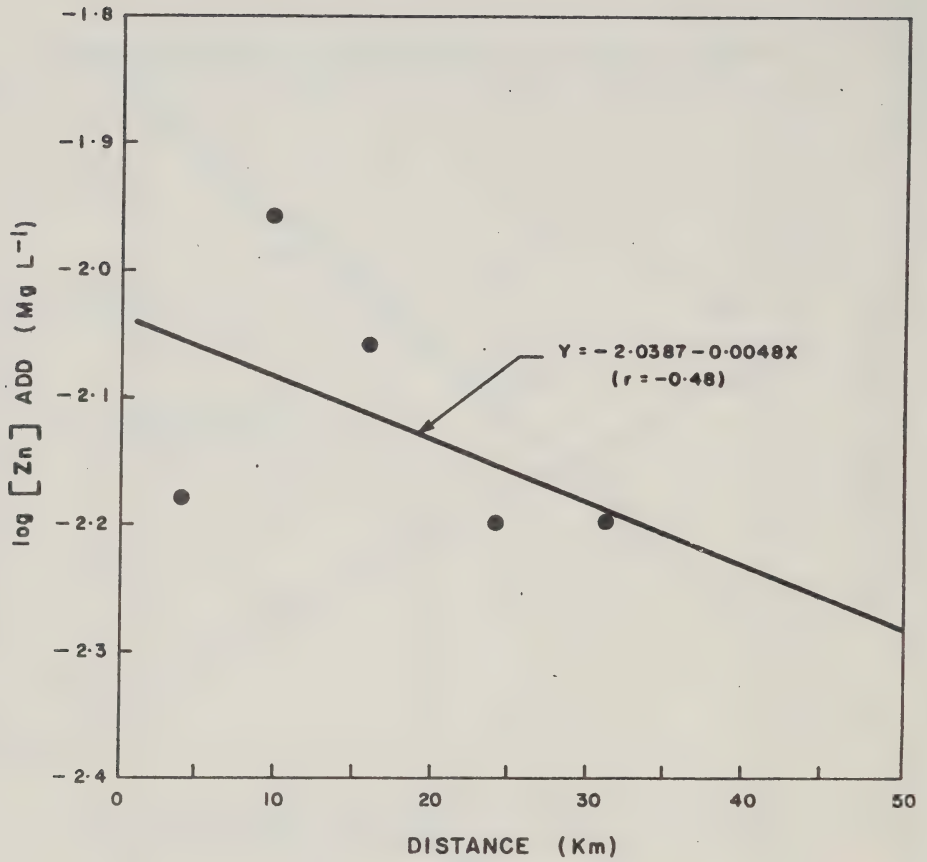


Figure 21: Dependence of Additional Zn Concentration on Distance from INCO Source

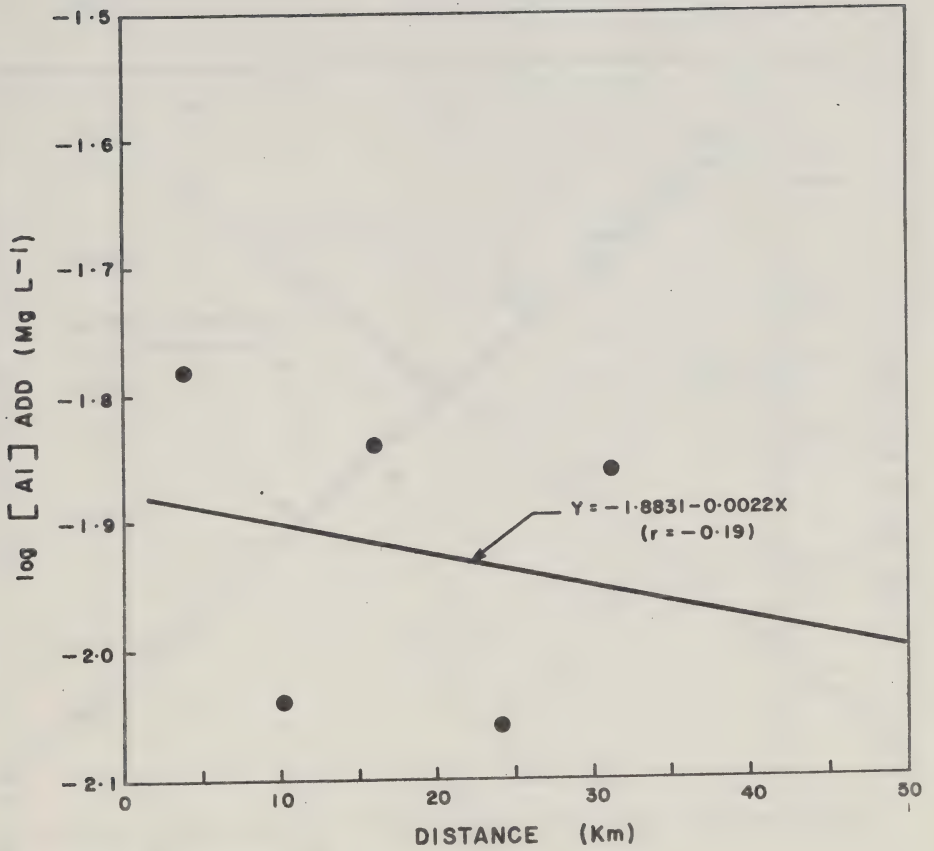


Figure 22: Dependence of Additional Al Concentration on Distance from INCO Source

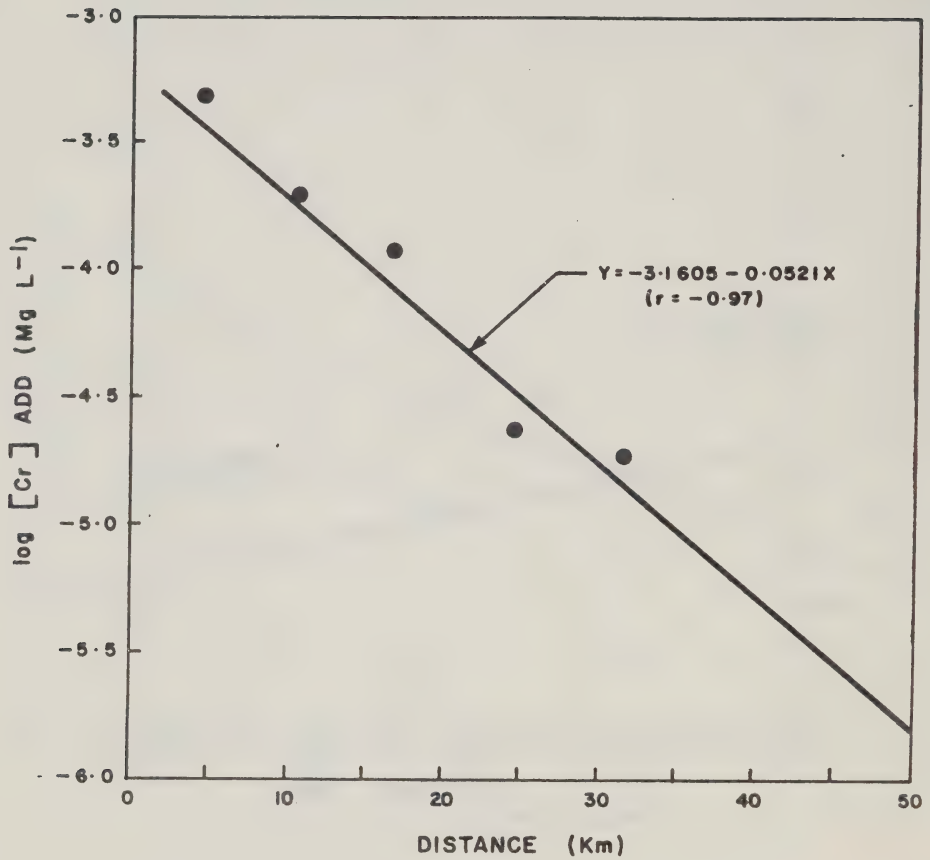


Figure 23: Dependence of Additional Cr Concentration on Distance from INCO Source

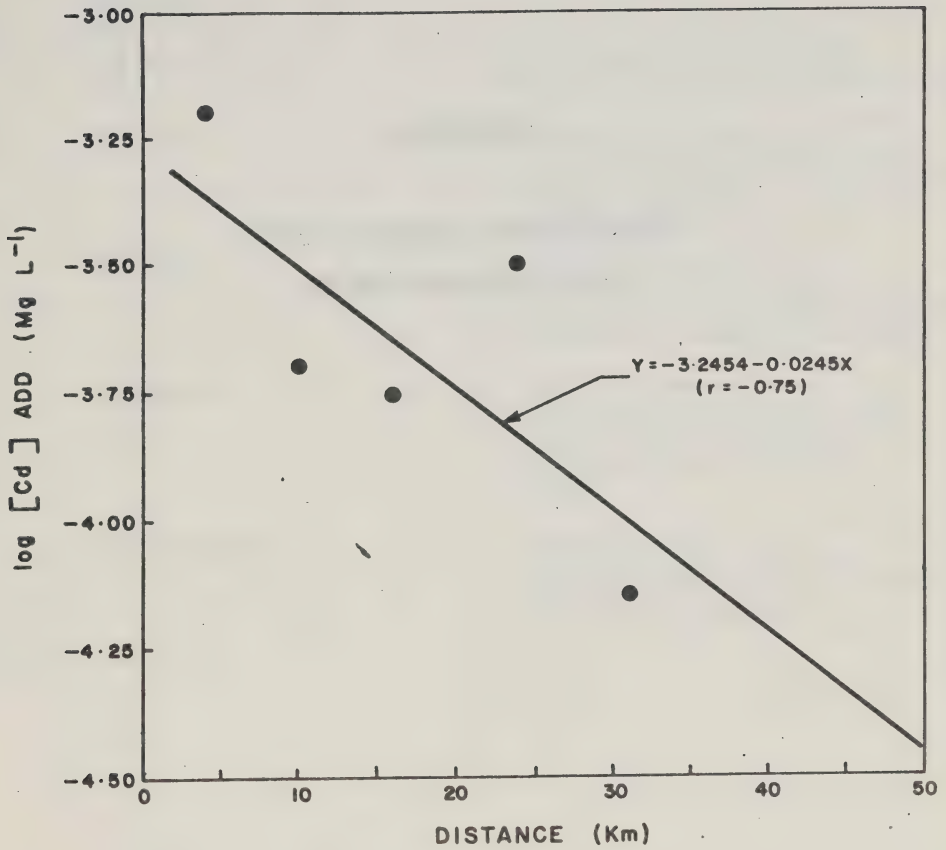


Figure 24: Dependence of Additional Cd Concentration on Distance from INCO Source

APPENDIX 1

Sampling Handling Criteria for Limited
Volume Precipitation Samples

APPENDIX 1

Sample Handling Criteria for Limited Volume Precipitation Samples

<u>Volume Collected (ml)</u>	<u>Handling Method</u>
Less than 50	<ul style="list-style-type: none">- pH measured at the field office- no sample submitted for chemical analysis
50 to 150	<ul style="list-style-type: none">- no field pH measured- no metals analyses submitted -total volume submitted for laboratory analysis of major ions and pH
150 to 250	<ul style="list-style-type: none">- no field pH measured- 25 ml placed in metals bottle- balance of volume submitted to laboratory for major ions, pH and acidity analysis.
250 to 500	<ul style="list-style-type: none">- field pH measured- 25 ml transferred to metals bottle- balance submitted to laboratory for ion, pH acidity and conductivity analysis.
greater than 500	<ul style="list-style-type: none">- field pH measured- metals bottle filled with 50 ml- balance submitted for ion, pH, acidity and conductivity analysis.

APPENDIX 2

Selected Precipitation Data Collected

in Sudbury in 1978 and 1979

Data are presented according to sampling date and sampling station. Except for volume (ml) and pH, data are all expressed in concentration units (mg l^{-1}). Station numbers are labelled according to Figure 2. Samples from stations which are affected by INCO alone, Falconbridge alone, INCO and Falconbridge together, and INCO primarily plus small contributions from Falconbridge are designated as I, F, + and N respectively after the station number under the heading P. Those labelled with X are not included in calculations because of suspected contamination. Others which are not labelled correspond to background data. The symbols W and C in the first column correspond to the type of weather front that the precipitation event is associated with, i.e. warm or cold front. All concentration data which are missing because of insufficient volume or for other reasons are replaced by a "-9.00". Any value preceded with a negative sign was not used in the calculations due to probable contamination. It should be noted that concentration of NO_3 and NH_4 are expressed as N-NO_3 and N-NH_4 in these Tables.

INCO & FAIRG OPERATING PERIOD SELECTED EVENTS

F	ST	P	VOL	HF	PH	ACID	504	MO3	MM4	CL	CA	HG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
780827																							
W	2		810.	0.191	3.72	7.91	4.80	0.52	0.354	0.16	1.10	0.01	0.04	0.03	9.00	0.016	0.001	0.001	0.014	0.016	0.007	0.0005	0.0001
W	3		1455.	0.141	3.85	9.38	4.35	0.41	0.302	0.11	0.21	0.01	0.04	0.02	9.00	0.048	0.001	0.001	0.012	0.046	0.026	0.0005	0.0001
W	5		2933.	0.079	4.10	5.55	3.80	0.43	0.302	0.11	0.19	0.01	0.06	0.03	9.00	0.018	0.001	0.001	0.009	0.037	0.002	0.0005	0.0001
W	9		2215.	0.056	4.25	7.17	3.40	0.44	0.240	0.09	0.15	0.02	0.04	0.04	9.00	0.011	0.001	0.001	0.008	0.008	0.005	0.0005	0.0001
W	10		2150.	0.028	4.55	9.57	3.60	0.20	0.238	0.14	0.37	0.03	0.07	0.03	9.00	0.008	0.001	0.001	0.007	0.008	0.004	0.0003	0.0001
780828																							
C	2	A	670.	0.123	3.91	13.60	5.00	0.69	0.950	0.26	0.19	0.04	0.13	0.12	9.00	0.029	0.013	0.005	0.018	0.148	0.011	0.0005	0.0012
C	3	I	1290.	0.045	4.35	1.60	1.50	0.12	0.146	0.04	0.19	0.01	0.03	0.02	9.00	0.041	0.025	0.007	0.009	0.015	0.019	0.0005	0.0001
C	4	I	150.	0.050	4.30	9.00	3.45	0.22	0.000	0.00	0.00	0.00	0.00	0.00	9.00	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
C	5	I	1153.	0.045	4.35	4.32	1.80	0.16	0.258	0.06	0.08	0.01	0.03	0.03	9.00	0.011	0.005	0.002	0.005	0.015	0.002	0.0005	0.0001
C	6		430.	0.023	4.64	2.06	1.10	0.10	0.150	0.04	0.13	0.02	0.05	0.03	0.01	0.012	0.001	0.001	0.004	0.004	0.006	0.0005	0.0001
C	7		1290.	0.013	4.90	3.21	1.95	0.12	0.800	0.15	0.07	0.03	0.17	0.25	0.03	0.015	0.001	0.001	0.006	0.004	0.008	0.0005	0.0001
C	8	F	2260.	0.083	4.08	5.38	3.90	0.34	0.320	0.06	0.18	0.02	0.06	0.09	0.01	0.019	0.001	0.001	0.010	0.008	0.025	0.0005	0.0001
C	16	F	1290.	0.026	4.58	1.22	1.50	0.09	0.250	0.21	0.08	0.04	0.03	0.07	9.00	0.045	0.003	0.001	0.006	0.008	0.031	0.0005	0.0001
C	17		575.	0.095	4.02	3.76	3.00	0.24	0.470	0.11	0.85	0.05	0.08	0.06	9.00	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
C	19	I	1075.	0.056	4.25	1.09	2.25	0.16	0.202	0.07	0.19	0.03	0.03	0.02	9.00	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
780829																							
C	2	I	251.	0.056	4.25	9.00	5.40	0.19	0.000	0.30	0.00	0.00	0.00	0.00	9.00	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
C	3		660.	0.028	4.55	1.36	0.70	0.06	0.076	0.08	0.21	0.01	0.04	0.04	9.00	0.017	0.023	0.007	0.005	0.004	0.003	0.0005	0.0001
C	4	I	375.	0.008	5.10	9.00	9.00	9.00	0.324	9.00	0.23	0.02	0.54	0.36	9.00	0.026	0.017	0.003	0.003	0.038	0.010	0.0005	0.0004
C	5	I	550.	0.081	4.09	5.27	4.45	0.06	0.224	0.08	0.38	0.08	0.08	0.06	0.02	0.080	0.067	0.049	0.012	0.005	0.021	0.0005	0.0007
C	7		325.	0.012	4.92	2.06	0.50	0.09	0.098	0.44	0.18	0.04	0.08	0.03	0.03	0.162	0.006	0.001	0.004	0.009	0.037	0.0005	0.0001
C	8		1355.	0.009	5.03	1.95	0.60	0.04	0.076	0.05	0.28	0.05	0.06	0.05	0.01	0.053	0.003	0.002	0.003	0.008	0.029	0.0040	0.0001
C	9		1625.	0.032	4.49	5.04	1.45	0.13	0.170	0.05	0.26	0.04	0.07	0.04	0.02	0.006	0.006	0.001	0.002	0.003	0.005	0.0005	0.0001

INCO & FAIRG OPERATING PERIOD SELECTED EVENTS

F	ST	P	VOL	WF	PH	ACID	SO ₄	NO ₃	NH ₄	CL	CA	MG	NA	K	F	FE	CU	NI	PR	ZN	AL	CR	CD
C	16	F	210.	0.078	4.11	-4.00	3.20	0.18	0.208	0.18	0.21	0.04	0.07	0.23	0.14	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
C	19	x	220.	0.043	4.08	-4.00	4.20	0.12	0.000	-9.00	-9.00	-9.00	-9.00	-9.00	0.00	1.200	1.090	0.570	0.080	0.051	0.034	0.0010	0.0124
C	21	x	1290.	0.028	4.55	1.20	0.70	0.07	0.090	0.17	0.10	0.01	0.11	0.13	0.00	0.023	0.001	0.001	0.002	0.008	0.010	0.0005	0.0001
780902																							
M	2		860.	0.050	4.30	2.29	3.90	0.43	0.440	0.07	0.52	0.06	0.04	0.03	0.01	0.021	0.002	0.001	0.009	0.013	0.010	0.0005	0.0001
M	5		6204.	0.076	4.12	4.58	3.25	0.25	0.346	0.05	0.39	0.05	0.07	0.06	0.04	0.023	0.006	0.002	0.007	0.008	0.009	0.0005	0.0001
M	6		430.	0.076	4.12	4.69	4.00	0.41	0.480	0.07	0.34	0.05	0.07	0.06	0.01	0.054	0.001	0.001	0.013	0.008	0.044	0.0005	0.0001
M	8	I	4545.	0.068	4.17	4.24	3.85	0.30	0.390	0.05	0.58	0.09	0.11	0.08	0.01	0.087	0.009	0.003	0.012	0.017	0.080	0.0070	0.0001
M	16	x	1290.	0.045	4.02	6.76	7.30	0.60	1.200	0.17	0.67	0.09	0.09	0.14	0.01	0.040	0.006	0.002	0.017	0.010	0.031	0.0005	0.0001
M	21		3335.	0.054	4.27	4.35	2.60	0.30	0.354	0.04	0.47	0.06	0.04	0.04	0.01	0.031	0.002	0.001	0.008	0.002	0.019	0.0005	0.0001
780906																							
M	2		2850.	0.074	4.13	6.07	2.50	0.34	0.710	0.10	0.38	0.05	0.05	0.06	0.02	0.081	0.008	0.002	0.007	0.015	0.049	0.0010	0.0003
M	5	x	420.	0.084	4.05	7.21	10.00	0.85	1.960	0.25	1.05	0.18	0.28	0.21	0.02	0.151	0.014	0.005	0.013	0.012	0.097	0.0005	0.0002
M	6	I	430.	0.082	4.21	4.58	5.00	0.39	0.740	0.07	0.39	0.07	0.07	0.06	0.03	0.106	0.044	0.025	0.016	0.007	0.072	0.0005	0.0006
M	7		550.	0.014	4.85	3.78	3.20	0.55	0.900	0.11	0.72	0.12	0.13	0.07	0.03	0.092	0.003	0.001	0.014	0.007	0.081	0.0005	0.0001
M	9	x	200.	0.132	3.86	4.05	8.31	0.22	0.400	-9.00	-9.00	-9.00	0.11	0.10	0.06	0.152	0.130	0.134	0.037	0.020	0.030	0.0005	0.0039
M	17	I	1505.	0.050	4.30	4.35	4.50	0.88	1.020	0.32	0.99	0.15	0.16	0.18	0.07	0.174	0.02	0.11	0.011	0.071	0.080	0.0005	0.0005
M	19	I	645.	0.085	4.07	6.29	6.85	0.53	0.970	0.15	0.65	0.12	0.10	0.09	0.04	0.118	0.039	0.015	0.015	0.032	0.072	0.0005	0.0003
780909																							
M	2	x	40.	0.141	3.85	-9.00	11.10	1.18	0.000	-9.00	-9.00	-9.00	-9.00	-9.00	0.00	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
M	5		580.	0.052	4.28	6.29	6.35	0.56	1.340	0.19	0.73	0.10	0.11	0.12	0.06	0.107	0.003	0.001	0.017	0.012	0.098	0.0005	0.0001
M	7	I	820.	0.123	3.91	7.88	4.10	0.62	1.190	0.15	0.80	0.11	0.12	0.08	0.01	0.119	0.010	0.004	0.022	0.017	0.069	0.0005	0.0001
M	9		825.	0.078	4.11	5.73	5.30	0.77	1.020	0.10	0.63	0.12	0.07	0.10	0.03	0.018	0.001	0.001	0.010	0.030	0.014	0.0005	0.0001
780910																							
M	2		655.	0.063	4.06	5.45	4.30	0.51	0.510	0.07	0.63	0.08	0.08	0.06	0.01	0.129	0.018	0.002	0.013	0.015	0.078	0.0005	0.0001
M	3	I	440.	0.191	3.72	14.69	10.30	1.06	1.210	0.27	1.16	0.17	0.16	0.10	0.07	0.290	0.012	0.003	0.025	0.009	0.147	0.0005	0.0001

INCO & FAIGG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	SO4	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
W 5	1040.	0.047	4.33	4.81	3.70	0.54	0.790	0.11	0.50	0.11	0.12	0.05	0.06	0.070	0.001	0.001	0.012	0.007	0.073	0.0005	0.0001
W 8 I	475.	0.138	3.86	8.59	10.10	1.00	1.630	0.20	0.00	0.00	0.00	0.00	0.03	0.118	0.014	0.006	0.023	0.029	0.123	0.0065	0.0003
W 9	350.	0.025	4.61	2.75	2.50	0.39	0.430	0.06	0.53	0.02	0.05	0.07	0.02	0.008	0.001	0.001	0.008	0.067	0.004	0.0005	0.0001
W 17 X	175.	0.126	3.40	9.00	8.55	1.10	1.430	0.09	0.94	0.00	0.22	0.37	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000
W 19	700.	0.045	4.02	7.10	5.75	0.81	1.090	0.19	0.51	0.09	0.14	0.09	0.02	0.078	0.005	0.002	0.013	0.018	0.061	0.0005	0.0002
W 21 I	740.	0.182	3.74	11.56	9.75	1.20	1.670	0.22	1.36	0.16	0.14	0.14	0.03	0.180	0.016	0.005	0.032	0.027	0.079	0.0005	0.0010
780911																					
C 2 I	370.	0.102	3.99	4.92	4.30	0.52	0.580	0.34	0.40	0.05	0.27	0.08	0.02	0.023	0.017	0.002	0.013	0.026	0.009	0.0005	0.0001
C 5 I	415.	0.076	4.12	5.50	3.60	0.62	0.780	0.12	0.13	0.02	0.08	0.05	0.04	0.052	0.012	0.007	0.016	0.012	0.023	0.0005	0.0001
C 8 X	125.	0.069	4.16	9.00	3.95	0.37	0.410	0.00	0.80	0.11	0.07	0.31	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000
C 19 I	350.	0.117	3.93	10.30	4.10	0.50	0.840	0.11	0.17	0.04	0.10	0.11	0.02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000
780914																					
W 2	3795.	0.100	4.00	6.76	3.35	0.34	0.182	0.11	0.12	0.01	0.06	0.04	0.01	0.007	0.001	0.001	0.011	0.002	0.006	0.0005	0.0001
W 3	1940.	0.105	3.98	7.21	4.20	0.48	0.302	0.13	0.12	0.02	0.05	0.03	0.03	0.018	0.003	0.001	0.010	0.010	0.009	0.0005	0.0001
W 5	2210.	0.115	3.94	6.87	4.25	0.40	0.276	0.15	0.14	0.01	0.08	0.03	0.03	0.011	0.001	0.001	0.010	0.008	0.008	0.0005	0.0001
W 8	2430.	0.132	3.88	6.53	4.10	0.36	0.190	0.08	0.19	0.04	0.08	0.01	0.02	0.011	0.001	0.001	0.007	0.012	0.014	0.0005	0.0001
W 9	2490.	0.126	3.90	7.21	4.50	0.53	0.334	0.08	0.25	0.07	0.09	0.04	0.03	0.010	0.001	0.001	0.014	0.011	0.005	0.0005	0.0001
W 16	1150.	0.093	4.03	7.44	4.95	0.47	0.480	0.07	0.44	0.04	0.06	0.06	0.02	0.012	0.001	0.001	0.009	0.008	0.010	0.0005	0.0001
W 19	1915.	0.065	4.19	5.27	4.50	0.27	0.004	0.21	0.09	0.02	0.33	0.06	0.02	0.072	0.010	0.004	0.020	0.048	0.038	0.0005	0.0002
W 21 F	2045.	0.126	3.90	8.02	5.35	0.46	0.272	0.08	0.14	0.02	0.08	0.06	0.02	0.015	0.003	0.001	0.012	0.010	0.010	0.0005	0.0001
780915																					
C 2 X	50.	0.042	4.38	8.00	2.51	0.48	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000
C 5	185.	0.021	4.67	8.00	1.35	0.28	0.550	0.00	0.13	0.04	0.16	0.09	0.00	0.037	0.011	0.002	0.008	0.015	0.033	0.0005	0.0001
C 9	175.	0.020	4.70	8.00	0.60	0.20	0.300	0.00	0.51	0.06	0.08	0.08	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000
C 16 F	2695.	0.079	4.10	3.92	2.55	0.24	0.142	0.05	0.10	0.03	0.03	0.01	0.02	0.008	0.001	0.001	0.008	0.013	0.006	0.0005	0.0006

INCO & FALRG OPERATING PERIOD SELECTED EVENTS

F	ST	P	VOL	HF	PH	ACID	SO4	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
C	19	I	315.	0.056	6.25	-9.00	3.00	0.134	0.360	-9.00	0.455	0.113	0.452	0.12	-9.00	0.057	0.022	0.020	0.011	0.008	0.020	0.0005	0.0001
790609																							
W	2		674.	0.135	3.67	10.52	7.70	1.31	0.970	0.26	0.35	0.06	0.06	0.08	0.04	0.020	0.002	0.001	0.013	0.018	0.014	0.0005	0.0004
W	5		1777.	0.071	4.15	8.32	6.75	0.72	0.895	0.19	0.21	0.05	0.08	0.08	0.04	0.036	0.002	0.001	0.012	0.010	0.022	0.0005	0.0004
W	7	I	1166.	0.068	4.17	8.70	7.25	0.68	0.710	0.20	0.13	0.04	0.06	0.07	0.04	0.046	0.017	0.007	0.014	0.008	0.007	0.0005	0.0005
W	16		414.	0.089	4.05	10.70	8.90	1.54	1.260	0.24	0.45	0.08	0.08	0.20	0.04	0.022	0.003	0.001	0.013	0.016	0.014	0.0005	0.0004
W	21	F	1722.	0.129	3.84	9.34	6.85	0.62	0.695	0.14	0.13	0.02	0.02	0.08	0.04	0.018	0.008	0.001	0.010	0.012	0.005	0.0005	0.0006
W	22		1481.	0.091	4.04	9.38	6.50	0.74	0.905	0.16	0.16	0.04	0.05	0.06	0.04	0.017	0.003	0.001	0.010	0.004	0.004	0.0005	0.0004
W	24	I	1365.	-9.000	-9.00	-9.00	9.55	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	0.009	0.006	-9.000	-9.000	-9.000	-9.000	-9.000
W	26		1656.	0.065	4.19	7.88	5.75	0.78	1.150	0.24	0.19	0.04	-9.00	-9.00	0.04	0.020	0.003	0.001	0.013	0.013	0.011	0.0005	0.0003
W	29		2323.	0.074	4.10	8.27	6.40	0.64	0.595	0.14	0.14	0.02	0.04	0.02	0.04	0.007	0.001	0.001	0.010	0.006	0.002	0.0005	0.0003
W	34		1130.	0.066	4.17	8.17	6.90	0.99	1.040	0.36	0.52	0.08	0.18	0.20	0.04	0.016	0.002	0.001	0.013	0.023	0.007	0.0005	0.0004
W	35		1183.	0.076	4.12	8.90	7.45	1.00	0.910	0.23	0.30	0.05	0.12	0.16	0.04	0.018	0.002	0.001	0.012	0.014	0.006	0.0005	0.0004
790621																							
W	4	X	65.	0.100	4.00	-9.00	9.25	1.57	-9.000	0.39	1.23	-9.00	-9.00	-9.00	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W	7	I	243.	-9.000	-9.00	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
W	16		163.	0.019	4.72	-9.00	3.65	0.52	0.550	0.17	0.76	-9.00	0.07	0.31	0.04	0.019	0.002	0.001	0.005	0.011	0.029	0.0005	0.0001
W	19	X	114.	0.050	4.30	-9.00	7.20	1.37	-9.000	0.35	-9.00	0.32	-9.00	-9.00	0.07	0.047	0.011	0.011	0.013	0.024	0.059	0.0005	0.0003
W	21	I	272.	0.043	4.37	-9.00	6.60	0.61	0.650	0.17	0.72	0.12	0.06	0.32	0.04	0.037	0.025	0.007	0.011	0.014	0.050	0.0005	0.0003
W	23		291.	0.035	4.45	5.60	4.00	0.60	-9.000	0.34	-9.00	0.12	0.17	-9.00	0.04	0.023	0.004	0.002	0.006	0.012	0.024	0.0005	0.0003
W	26		403.	0.066	4.18	5.67	4.50	0.63	0.600	0.26	0.60	0.10	0.12	0.03	0.07	0.035	0.003	0.002	0.008	0.012	0.019	0.0005	0.0001
W	29		229.	0.039	4.41	-9.00	3.65	0.53	0.450	0.16	0.38	0.08	0.06	0.36	0.04	0.015	0.001	0.001	0.007	0.013	0.011	0.0005	0.0001
W	34		415.	0.040	4.40	3.53	4.60	0.72	0.910	0.85	1.10	0.17	0.38	0.71	0.04	0.031	0.008	0.003	0.008	0.032	0.038	0.0005	0.0008
W	35	X	115.	0.047	4.33	-9.00	17.25	1.44	-9.000	0.44	-9.00	0.68	0.27	-9.00	0.06	0.099	0.072	0.044	0.039	0.044	0.103	0.0005	0.0012

INCO & FALOG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	SO4	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	P8	ZN	AL	CR	CO
W 36 I	160.	0.030	4.52	-9.00	10.40	0.97	2.500	0.29	0.90	0.22	0.13	0.24	0.05	0.134	0.159	0.123	0.040	0.028	0.147	0.0025	0.0086
W 37	349.	0.041	4.39	5.38	3.05	0.52	0.400	0.38	0.36	0.06	0.10	-9.00	0.06	0.037	0.005	0.002	0.007	0.015	0.032	0.0005	0.0004
790623																					
C 2 I	91.	0.044	4.36	-9.00	3.15	0.10	0.050	0.16	0.11	0.02	-9.00	-9.00	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
C 4 I	133.	0.013	4.90	-9.00	1.35	0.09	0.190	0.23	0.17	0.03	0.05	0.09	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
C 5 I	61.	0.031	4.51	-9.00	2.55	0.08	-9.000	0.11	-9.00	0.03	-9.00	-9.00	0.04	0.055	0.003	0.002	0.004	0.006	0.035	0.0005	0.0001
C 21	58.	0.012	4.91	-9.00	0.70	0.12	-9.000	0.21	0.20	0.04	-9.00	-9.00	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
C 24	154.	-9.000	-9.00	-9.00	0.65	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	0.001	0.001	-9.000	-9.000	-9.000	-9.000	-9.000
C 26	114.	0.005	5.31	-9.00	0.30	0.03	-9.000	0.15	0.22	0.04	0.03	0.17	0.04	0.010	0.002	0.001	0.001	0.006	0.006	0.0005	0.0001
C 34 F	325.	0.009	5.06	1.98	0.50	0.07	0.050	0.17	0.47	0.02	0.08	-9.00	0.04	0.004	0.001	0.001	0.003	0.008	0.002	0.0005	0.0002
C 35 Y	62.	0.000	6.44	-9.00	0.65	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
790626																					
W 2 I	435.	0.045	4.35	7.16	7.65	1.17	0.660	0.32	1.75	-0.42	0.07	0.13	0.04	0.045	0.002	0.001	0.014	0.020	0.052	0.0005	0.0002
W 5 I	534.	0.032	4.50	10.48	8.85	1.56	1.050	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W 16 +	724.	0.072	4.14	7.59	8.55	-1.90	0.840	0.36	-2.96	-0.60	0.06	0.13	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W 21	3666.	0.060	4.22	6.03	5.10	0.64	0.480	0.12	0.74	0.19	0.03	0.07	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W 24	3366.	0.074	4.13	6.53	5.05	0.78	0.500	0.19	0.91	0.18	0.01	0.03	0.04	0.022	0.001	0.001	0.011	0.012	0.015	0.0005	0.0001
W 26 I	1875.	0.065	4.19	8.86	9.40	-1.93	0.910	0.33	-2.56	-0.66	0.09	0.16	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W 29	1854.	0.066	4.18	4.93	5.90	1.00	0.520	0.20	1.46	0.32	0.03	0.07	0.04	0.022	0.001	0.001	0.010	0.008	0.028	0.0005	0.0001
W 35 I	1744.	0.062	4.21	6.47	8.55	1.67	0.810	0.24	1.68	-0.55	0.06	0.11	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
790630																					
W 2 F	672.	0.102	3.99	12.72	9.50	0.82	0.810	0.22	0.10	0.03	0.08	0.06	0.04	0.014	0.001	0.001	0.025	0.008	0.005	0.0005	0.0003
W 4 F	723.	0.151	3.82	15.14	12.70	0.85	1.200	0.19	0.21	0.03	0.09	0.08	0.04	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W 5 F	1015.	0.224	3.65	14.68	11.10	0.90	0.930	0.22	0.10	0.03	0.08	0.05	0.04	0.031	0.001	0.001	0.021	0.008	0.010	0.0005	0.0003
W 7	797.	0.158	3.80	10.78	7.85	0.51	0.550	0.12	0.09	0.02	0.06	0.02	0.04	0.021	0.001	0.001	0.019	0.015	0.005	0.0005	0.0002

INCO & FALBG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	504	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
W 16	999.	0.100	4.00	9.24	6.65	0.54	0.570	0.22	0.16	0.03	0.12	0.07	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
W 21	4767.	0.054	4.27	5.86	3.35	0.15	0.330	0.04	0.08	0.01	0.02	0.01	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
W 22 X	1829.	0.214	3.66	13.96	14.25	0.60	0.710	1.19	1.68	0.41	0.60	0.14	0.04	0.039	0.022	0.008	0.023	0.020	0.025	0.0005	0.0013
W 24	3771.	0.117	3.93	8.63	6.55	0.44	0.680	0.17	0.15-9.00	0.05	0.37	0.04	0.023	0.002	0.003	0.014	0.010	0.010	0.0005	0.0003	0.0003
W 25	1691.	0.102	3.99	9.61	6.65	0.52	0.680	0.12	0.12	0.02	0.04	0.05	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
W 26 F	858.	0.115	3.94	11.39	6.55	0.44	0.680	0.12	0.12	0.02	0.07	0.03	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
W 29 M	2216.	0.174	3.76	11.13	6.55	0.49	0.530	0.12	0.04	0.01	0.26	0.03	0.04	0.014	0.007	0.001	0.016	0.006	0.002	0.0005	0.0003
W 34	752.	0.146	3.83	10.12	7.70	0.52	0.680	0.49	0.15	0.03	0.24	0.29	0.03	0.019	0.003	0.001	0.016	0.062	0.004	0.0005	0.0003
790701																					
C 2 F	3048.	0.028	4.55	4.37	1.75	0.10	0.130	0.09	0.04	0.02	0.04	0.04	0.04	0.006	0.001	0.001	0.008	0.005	0.001	0.0005	0.0001
C 4 F	2069.	0.072	4.14	7.24	4.10	0.32	0.300	0.11	0.07	0.02	0.06	0.02	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
C 5 F	1371.	0.087	4.06	6.10	3.35	0.31	0.260	0.10	0.01	0.01	0.06	0.03	0.04	0.012	0.001	0.001	0.013	0.003	0.002	0.0005	0.0001
C 7 F	429.	0.107	3.97	9.85	7.95	0.57	0.450	0.29	0.17	0.02	0.15	0.07	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
C 16	2899.	0.044	4.36	5.27	2.15	0.29	0.270	0.12	0.09	0.01	0.07	0.03	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
C 21	2801.	0.035	4.45	4.14	2.05	0.18	0.190	0.15	0.06	0.02	0.07	0.03	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
C 25 F	578.	0.117	3.93	11.20	9.45	0.69	0.610	0.18	0.18	0.02	0.09	0.05	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
C 26 F	855.	0.081	4.09	6.15	4.95	0.18	0.220	0.13	0.13	0.01	0.09	0.07	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
C 29 M	3881.	0.095	4.02	6.25	3.80	0.17	0.210	0.06	0.04	0.01	0.02	0.01	0.04	0.005	0.002	0.001	0.010	0.004	0.001	0.0005	0.0001
C 34	2078.	0.059	4.23	4.77	2.25	0.25	0.220	0.12	0.04	0.01	0.08	0.08	0.04	0.013	0.001	0.001	0.008	0.024	0.003	0.0010	0.0001
C 35 F	806.	0.046	4.32	5.53	2.85	0.27	0.260	0.11	0.09	0.02	0.06	0.07	0.04	-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000-9.000							
790724																					
W 2	1057.	0.046	4.32	5.22	3.50	0.16	0.280	0.12	0.24	0.05	0.06	0.23	0.04	0.010	0.001	0.001	0.008	0.010	0.005	0.0005	0.0001
W 5	1328.	-9.000	-9.00	-9.00	3.45	-9.00-9.000	-9.000														
W 7 I	2077.	0.051	4.29	6.15	3.80	0.37	0.440	0.11	0.29	0.02	0.03	0.29	0.04	0.018	0.017	0.018	0.007	0.009	0.013	0.0005	0.0002

INCO & FALRG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	SO4	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CO
W 17	961.	0.078	4.11	6.14	3.40	0.53	0.340	0.12	0.19	0.05	0.06	0.02	0.04	0.016	0.001	0.001	0.009	0.014	0.009	0.0005	0.0001
W 19	647.	0.074	4.13	6.96	4.20	0.61	0.340	0.19	0.38	0.08	0.08	0.04	0.04	0.003	0.004	0.002	0.011	0.028	0.063	0.0005	0.0002
W 21 I	1369.	0.076	4.12	5.86	4.25	0.33	0.400	0.09	0.20	0.17	0.02	0.02	0.04	0.046	0.025	0.011	0.011	0.014	0.013	0.0010	0.0005
W 22	2702.	0.072	4.14	5.74	3.35	0.35	0.320	0.08	0.06	0.01	0.06	0.01	0.04	0.008	0.001	0.001	0.007	0.007	0.007	0.0005	0.0002
W 23	1770.	0.066	4.18	6.12	3.65	0.44	0.320	0.25	0.27	0.05	0.04	0.05	0.04	0.072	0.006	0.002	0.008	0.027	0.094	0.0010	0.0006
W 24	440.	0.044	4.31	4.44	3.10	0.39	0.490	0.14	0.24	0.05	0.04	0.16	0.04	0.011	0.003	0.001	0.007	0.011	0.006	0.0005	0.0001
W 26	653.	0.063	4.20	5.53	4.15	0.60	0.630	0.02	0.42	0.04	0.22	0.15	0.04	0.028	0.005	0.009	0.008	0.019	0.014	0.0005	0.0001
W 28	1148.	0.081	4.09	7.42	4.35	0.67	0.500	0.18	0.33	0.07	0.04	0.06	0.04	0.072	0.003	0.001	0.012	0.032	0.089	0.0005	0.0003
W 29	3558.	0.066	4.18	5.54	4.00	0.45	0.550	0.12	0.04	0.02	0.03	0.05	0.04	0.008	0.004	0.001	0.009	0.012	0.005	0.0005	0.0001
W 35 I	913.	0.087	4.06	6.94	5.45	0.77	0.590	0.21	0.00	0.01	0.18	0.18	0.04	0.027	0.006	0.003	0.018	0.027	0.028	0.0010	0.0002
W 36 I	1878.	0.063	4.20	5.41	3.95	0.30	0.280	0.08	0.13	0.04	0.04	0.03	0.04	0.109	0.042	0.019	0.010	0.012	0.079	0.0005	0.0002
W 37	1722.	0.069	4.16	5.52	3.35	0.45	0.280	0.38	0.37	0.04	0.08	0.05	0.04	0.110	0.003	0.001	0.008	0.019	0.086	0.0010	0.0001
790725																					
C 2	439.	0.039	4.41	3.41	1.45	0.15	0.120	0.04	0.01	0.01	0.02	0.01	0.04	0.002	0.001	0.001	0.003	0.006	0.009	0.0005	0.0001
C 4 F	2671.	0.048	4.32	5.33	3.70	0.35	0.300	0.14	0.09	0.05	0.07	0.41	0.04	0.007	0.002	0.001	0.014	0.000	0.000	0.0000	0.0000
C 5 F	1345.	0.087	4.06	6.83	4.25	0.48	0.560	0.13	0.07	0.02	0.06	0.05	0.04	0.027	0.001	0.001	0.009	0.027	0.119	0.0020	0.0000
C 7 I	5037.	0.055	4.26	6.56	3.15	0.29	0.280	0.07	0.05	0.02	0.03	0.01	0.04	0.008	0.002	0.001	0.007	0.006	0.005	0.0005	0.0001
C 16 X	2432.	0.069	4.05	7.72	5.25	0.51	0.480	0.10	0.06	0.01	0.05	0.05	0.04	0.007	0.001	0.001	0.009	0.007	0.005	0.0005	0.0001
C 17 N	1532.	0.072	4.14	5.69	3.10	0.24	0.200	0.04	0.04	0.01	0.03	0.01	0.04	0.010	0.007	0.001	0.005	0.005	0.006	0.0005	0.0003
C 19 F	2951.	0.033	4.03	6.92	4.35	0.42	0.340	0.09	0.05	0.01	0.05	0.01	0.04	0.013	0.003	0.001	0.008	0.012	0.006	0.0005	0.0002
C 21 I	2129.	0.054	4.27	4.34	2.55	0.11	0.140	0.04	0.03	0.04	0.01	0.01	0.04	0.007	0.008	0.001	0.005	0.006	0.005	0.0005	0.0002
C 22 N	1595.	0.074	4.10	6.42	4.40	0.38	0.360	0.07	0.07	0.02	0.04	0.03	0.04	0.019	0.002	0.001	0.007	0.012	0.008	0.0005	0.0002
C 23 F	3423.	0.068	4.17	6.73	4.45	0.34	0.330	0.14	0.07	0.02	0.08	0.04	0.04	0.029	0.008	0.002	0.008	0.041	0.010	0.0005	0.0005

INCO & FALRG OPERATING PERIOD SELECTED EVENTS

F ST #	WOL	HF	PH	ACID	504	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
C 24	914.	0.028	4.55	2.71	1.45	0.08	0.110	0.04	0.02	0.04	0.01	0.02	0.04	0.005	0.003	0.001	0.003	0.008	0.006	0.0005	0.0001
C 26 F	898.	0.078	4.11	6.81	4.10	0.38	0.360	0.08	0.04	0.04	0.02	0.01	0.04	0.013	0.004	0.001	0.008	0.009	0.005	0.0005	0.0001
C 28 M	3210.	0.083	4.08	6.41	4.80	0.36	0.380	0.29	0.06	0.03	0.07	0.03	0.04	0.052	0.069	0.019	0.011	0.022	0.009	0.0005	0.0007
C 29 M	673.	0.060	4.22	4.76	2.75	0.31	0.190	0.07	0.03	0.02	0.01	0.01	0.04	0.006	0.003	0.001	0.004	0.009	0.005	0.0005	0.0001
C 30 M	2897.	0.105	3.98	8.19	5.35	0.46	0.420	0.10	0.04	0.01	0.07	0.02	0.03	0.038	0.017	0.004	0.014	0.021	0.017	0.0005	0.0006
C 34	6788.	0.034	4.47	3.52	2.65	0.24	0.260	0.63	0.19	0.03	0.46	0.26	0.04	0.001	0.002	0.003	0.006	0.010	0.005	0.0005	0.0001
C 35 I	2452.	0.081	4.09	6.67	4.55	0.40	0.340	0.09	0.00	0.05	0.09	0.01	0.04	0.010	0.004	0.001	0.011	0.008	0.005	0.0005	0.0001
C 36 M	1857.	0.051	4.29	5.92	4.20	0.28	0.540	0.06	0.03	0.03	0.05	0.01	0.04	0.012	0.007	0.003	0.008	0.012	0.005	0.0005	0.0001
C 37 N	3333.	0.129	3.89	8.64	6.20	0.42	0.420	0.20	0.13	0.03	0.12	0.06	0.04	0.058	0.068	0.031	0.015	0.056	0.017	0.0005	0.0008
790728																					
W 4	509.	0.052	4.28	5.50	5.50	0.80	0.730	0.16	0.98	0.08	0.01	0.08	0.03	0.020	0.004	0.001	0.040	0.013	0.024	0.0005	0.0001
W 16	1588.	0.065	4.19	6.81	5.50	0.44	0.680	0.27	0.19	0.01	0.09	0.09	0.04	0.032	0.013	0.003	0.011	0.012	0.027	0.0005	0.0004
W 19 X	89.	0.141	3.85	9.00	18.15	2.65	9.000	1.11	9.00	9.00	9.00	9.00	0.10	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
W 21 I	293.	9.000	-3.64	-9.00	11.80	1.20	0.640	0.24	-9.00	0.01	-9.00	0.03	0.05	0.044	0.017	0.007	0.032	0.018	0.011	0.0005	0.0004
W 28 X	62.	-9.000	-9.00	-9.00	18.70	2.31	-9.000	0.88	-9.00	-9.00	-9.00	-9.00	0.16	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
W 36 X	89.	0.331	3.48	-9.00	28.35	3.52	9.000	0.98	-9.00	-9.00	-9.00	-9.00	0.16	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
790801																					
C 16 M	4873.	0.013	4.87	1.96	7.10	0.09	0.100	0.62	0.02	0.01	0.01	0.01	0.00	0.002	0.002	0.001	0.002	0.007	0.005	0.0005	0.0001
C 17 M	958.	0.023	4.64	2.85	1.20	0.22	0.060	0.06	0.16	0.12	0.01	0.01	0.04	0.053	0.011	0.004	0.004	0.016	0.025	0.0010	0.0002
C 19 F	787.	0.009	5.05	2.15	0.85	0.26	0.190	0.11	0.23	0.05	0.05	0.08	0.04	0.104	0.008	0.004	0.008	0.026	0.061	0.0020	0.0005
C 22 M	721.	0.058	4.24	4.41	2.60	0.22	0.110	0.08	0.15	0.06	0.01	0.01	0.04	0.010	0.037	0.009	0.005	0.007	0.005	0.0005	0.0002
C 23 F	749.	0.015	4.82	2.36	0.90	0.30	0.070	0.36	0.36	0.02	0.02	0.05	0.04	0.136	0.010	0.004	0.007	0.029	0.098	0.0025	0.0006
C 24 M	93.	0.032	4.49	-9.00	2.30	0.50	0.770	0.08	-9.00	-9.00	-9.00	-9.00	0.03	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000	-9.000
C 25 M	893.	0.030	4.53	3.41	2.30	0.12	0.230	0.24	0.20	0.06	0.12	0.33	0.04	0.020	0.025	0.009	0.004	0.049	0.001	0.0005	0.0005

INCO & FALING OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	MF	PH	ACID	SO4	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
C 26	1665.	0.021	4.67	2.89	1.00	0.09	0.100	0.03	0.06	0.03	0.01	0.01	0.04	0.005	0.003	0.001	0.003	0.001	0.0005	0.0001
C 28 F	659.	0.020	4.69	2.36	0.85	0.31	0.150	0.11	0.27	0.10	0.05	0.04	0.04	0.048	0.010	0.004	0.006	0.017	0.021	0.0015
C 29 N	875.	0.032	4.49	-9.00	1.30	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	0.009	0.001	-9.000	-9.000	-9.0000	-9.0000
C 34 X	919.	0.026	4.58	3.68	2.05	0.20	0.370	0.17	0.17	0.04	0.05	0.10	0.04	0.013	0.003	0.001	0.008	0.014	0.004	0.0005
C 35 F	1215.	0.044	4.36	3.62	1.50	0.15	0.090	0.07	0.10	0.01	0.02	0.01	0.00	0.007	0.003	0.001	0.004	0.009	0.002	0.0005
C 36 N	1062.	0.041	4.39	3.96	1.90	0.19	0.030	0.05	0.11	0.01	0.01	0.01	0.04	0.081	0.006	0.002	0.007	0.015	0.032	0.0015
C 37	913.	0.017	4.76	2.43	1.30	0.23	0.200	0.11	0.19	0.35	0.01	0.01	0.04	0.060	0.006	0.001	0.004	0.013	0.065	0.0010
790802																				
C 2 N	2437.	0.016	4.80	2.28	0.60	0.06	0.050	0.04	1.02	0.01	0.01	0.01	0.04	0.021	0.005	0.001	0.024	0.016	0.021	0.0010
C 4 M	1326.	0.026	4.55	3.38	1.70	0.06	0.140	0.10	0.02	0.02	0.01	0.01	0.04	0.012	0.023	0.005	0.004	0.009	0.005	0.0005
C 5 M	634.	0.021	4.68	3.51	2.05	0.11	0.280	0.53	0.15	0.01	0.20	0.22	0.04	0.027	0.011	0.005	0.004	0.100	0.010	0.0005
C 16 F	876.	0.026	4.58	2.63	2.05	0.23	0.050	0.10	0.05	0.01	0.01	0.01	0.02	0.009	0.001	0.002	0.001	0.006	0.005	0.0005
C 17 I	627.	0.048	4.32	4.99	3.00	0.15	0.010	0.17	0.10	0.07	0.08	0.04	0.04	0.013	0.011	0.004	0.004	0.032	0.005	0.0005
C 19 I	1293.	0.024	4.62	3.01	1.40	0.11	0.080	0.07	0.06	0.01	0.02	0.02	0.04	0.038	0.007	0.004	0.004	0.061	0.013	0.0050
C 21	252.	-9.000	-9.00	-9.00	0.80	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.000	0.002	0.001	-9.000	-9.000	-9.0000	-9.0000
C 22	513.	0.042	4.38	3.41	1.70	0.18	0.710	0.10	0.18	0.01	0.02	0.02	0.04	0.010	0.003	0.001	0.003	0.006	0.005	0.0005
C 23 I	1143.	0.047	4.33	4.54	3.55	0.11	0.230	0.14	0.08	0.09	0.03	0.02	0.04	0.220	0.280	0.065	0.036	0.038	0.026	0.0015
C 28 I	1187.	0.025	4.60	2.82	2.25	0.08	0.460	0.05	0.06	0.06	0.01	0.01	0.04	0.044	0.069	0.017	0.007	0.040	0.010	0.0045
C 35	609.	0.037	4.43	3.21	1.35	0.15	0.070	0.07	0.05	0.01	0.03	0.01	0.00	0.010	0.011	0.003	0.004	0.011	0.005	0.0005
C 36	258.	0.028	4.56	-9.00	1.20	0.29	0.170	0.51	-9.00	0.03	-9.00	-9.00	0.04	0.035	0.008	0.006	0.005	0.070	0.026	0.0025
C 37 N	1403.	0.026	4.59	3.74	2.20	0.08	0.180	0.17	0.10	0.04	0.09	0.04	0.04	0.048	0.020	0.007	0.007	0.036	0.024	0.0005
790806																				
C 5 K	1196.	0.012	4.92	2.12	8.25	0.65	0.220	0.17	0.25	0.03	0.03	0.10	0.08	0.053	0.005	0.001	0.004	0.007	0.029	0.0005
C 7 I	2126.	0.020	4.69	2.90	2.05	0.03	0.010	0.05	0.33	0.13	0.04	0.36	0.04	0.046	0.006	0.006	0.003	0.057	0.013	0.0065

INCO & FALBG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	SO4	NH4	CL	CA	HG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD	
C 16	1599.	0.032	4.50	3.16	1.30	0.19	0.240	0.07	0.24	0.03	0.02	0.04	0.00	0.014	0.005	0.002	0.004	0.014	0.006	0.0010	0.0002
C 21 I	1747.	0.058	4.24	4.32	2.80	0.21	0.260	0.10	0.27	0.02	0.04	0.06	0.04	0.015	0.005	0.001	0.003	0.002	0.009	0.0005	0.0002
C 24	1662.	0.011	4.95	2.64	1.00	0.20	0.660	0.06	0.16	0.02	0.05	0.06	0.01	0.012	0.001	0.001	0.002	0.003	0.009	0.0005	0.0001
C 25 A	860.	0.000	7.15	9.00	1.50	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.000	0.001	0.001	9.000-9.000	9.000-9.000	9.0000	9.0000	
C 26	1306.	0.015	4.82	2.30	1.15	0.15	0.160	0.05	0.23	0.02	0.03	0.03	0.04	0.013	0.015	0.004	0.004	0.005	0.001	0.0005	0.0003
C 29	3447.	0.020	4.69	2.36	0.95	0.13	0.170	0.07	0.12	0.05	0.01	0.01	0.04	0.007	0.001	0.001	0.002	0.003	0.001	0.0010	0.0001
C 34	2450.	9.000	9.00	9.00	0.75	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.000	0.003	0.001	9.000-9.000	9.000-9.000	9.0000	9.0000	
C 35	1521.	0.004	5.45	9.00	0.95	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.000	0.003	0.003	9.000-9.000	9.000-9.000	9.0000	9.0000	
790809																					
C 5	634.	0.028	4.55	4.04	0.95	0.14	0.080	0.08	0.07	0.01	0.05	0.04	0.04	0.059	0.005	0.002	0.005	0.008	0.018	0.0005	0.0001
C 16	630.	0.013	4.88	3.02	1.50	0.20	0.130	0.02	0.09	0.01	0.02	0.03	0.04	0.007	0.002	0.001	0.003	0.006	0.005	0.0005	0.0001
C 17	1365.	0.022	4.66	2.83	0.80	0.13	0.070	0.02	0.07	0.16	0.01	0.01	0.04	0.010	0.003	0.001	0.005	0.001	0.001	0.0005	0.0001
C 19	554.	0.021	4.88	2.65	1.05	0.17	0.120	0.16	0.20	0.37	0.10	0.05	0.04	0.089	0.006	0.004	0.008	0.081	0.043	0.0070	0.0002
C 21 I	199.	0.026	4.59	9.00	2.50	-1.74-9.000	0.48-9.00	0.02	0.03	0.01	-0.18	-9.000-9.000	9.000-9.000	9.000-9.000	9.000-9.000	9.000-9.000	9.000-9.000	9.000-9.000	9.0000	9.0000	
C 22 I	738.	0.015	4.83	2.59	1.30	0.12	0.160	0.13	0.12	0.02	0.04	0.10	0.01	0.036	0.017	0.020	0.005	0.039	0.005	0.0045	0.0002
C 26	437.	0.025	4.60	2.77	1.00	0.18	0.140	0.05	0.08	0.01	0.03	0.05	0.04	0.023	0.001	0.001	0.006	0.006	0.003	0.0005	0.0001
C 28	656.	0.025	4.60	2.76	1.00	0.17	0.110	0.15	0.09	0.05	0.07	0.11	0.04	0.057	0.005	0.001	0.005	0.004	0.015	0.0005	0.0001
C 29 I	744.	0.030	4.53	2.80	0.95	0.17	0.070	0.03	0.10	0.01	0.01	0.01	0.02	0.005	0.001	0.001	0.004	0.002	0.005	0.0005	0.0001
C 34	740.	0.035	5.46	2.99	1.30	0.16	0.130	0.14	0.06	0.01	0.05	0.16	0.01	0.081	0.001	0.002	0.004	0.005	0.010	0.0060	0.0001
C 35	334.	0.036	4.44	3.24	9.00	0.22	0.170	0.10	0.19	0.01	0.02	0.05	0.00	0.017	0.004	0.002	0.009	0.019	0.006	0.0010	0.0001
C 37	761.	9.000	9.00	9.00	1.00	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.00-9.000	9.000	0.004	0.001	9.000-9.000	9.000-9.000	9.0000	9.0000	
790817																					
W 5	841.	0.115	3.94	8.60	5.00	1.04	0.580	0.24	0.43	0.07	0.05	0.07	0.00	0.201	0.002	0.001	0.021	0.024	0.108	0.0005	0.0001
W 19	1268.	0.087	4.06	10.31	6.35	1.38	2.500	1.52	0.42-9.00	0.06	1.48	0.16		0.129	0.003	0.001	0.020	0.017	0.078	0.0010	0.0002

INCO & FALG OPERATING PERIOD SELECTED EVENTS

F	ST	P	VOL	HF	PH	ACID	S04	NO3	MM%	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
W	21	I	1615.	0.126	3.90	9.81	6.20	0.84	0.500	0.19	0.26	0.03	0.01	0.01	0.09	0.000	0.061	0.016	0.026	0.013	0.007	0.0005	0.0010
W	24		1521.-	0.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.027	0.004	0.001	0.029	0.012	0.020	0.0005	0.0002
W	26	X	1233.-	0.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.039	0.016	0.009	0.025	0.008	0.007	0.0005	0.0012
W	28		879.	0.151	3.02	11.59	5.35	1.34	0.560	0.21	0.47	0.07	0.03	0.01	0.02	0.053	0.002	0.001	0.014	0.017	0.032	0.0005	0.0001
W	35		1010.	0.120	3.92	8.67	5.05	1.11	0.540	0.19	0.37	0.05	0.03	0.04	0.04	0.027	0.003	0.001	0.017	0.019	0.009	0.0050	0.0001
W	36	I	1314.	0.102	3.74	12.29	7.90	1.20	0.680	0.23	0.46	0.08	0.05	0.03	0.11	0.212	0.027	0.057	0.046	0.031	0.050	0.0010	0.0006
W	37		736.	0.110	3.96	10.21	5.60	1.46	0.680	0.49	0.62	0.09	0.06	0.04	0.09	0.141	0.003	0.002	0.018	0.022	0.044	0.0010	0.0002
790820																							
C	2	X	216.	0.005	4.07	-9.00	9.30	0.54	0.390	0.21	-9.00	0.01	0.07	0.98	0.14	0.087	0.009	0.004	0.012	0.069	0.054	0.0040	0.0004
C	5		589.	0.091	4.04	10.08	8.50	0.18	0.420	0.12	0.18	0.03	0.07	0.11	0.04	0.084	0.037	0.012	0.020	0.004	0.034	0.0005	0.0008
C	17		1767.	0.035	4.46	3.90	1.10	0.07	0.160	0.33	0.04	0.01	0.03	0.02	0.00	0.013	0.007	0.003	0.004	0.009	0.005	0.0005	0.0001
C	19	I	251.	0.123	3.91	-9.00	4.85	0.47	-9.000	0.63	-9.00	0.05	0.09	-9.00	-9.00	0.270	0.093	0.051	0.021	0.015	0.024	0.0005	0.0011
C	21	I	4589.	0.107	3.97	8.83	4.65	0.12	0.130	0.08	0.06	0.01	0.01	0.01	0.05	0.034	0.010	0.001	0.012	0.008	0.011	0.0005	0.0008
C	23	I	321.	0.200	3.70	-9.00	4.55	1.14	0.700	0.32	0.44	0.06	0.19	-9.00	0.05	0.270	0.137	0.066	0.023	0.021	0.032	0.0010	0.0011
C	28	I	732.	0.166	3.78	11.54	8.90	0.22	0.390	0.16	0.18	0.03	0.02	0.01	0.06	0.102	0.133	0.039	0.017	0.014	0.020	0.0005	0.0008
C	29		856.	0.032	4.50	3.06	1.15	0.08	0.130	0.09	0.05	0.01	0.05	0.02	0.11	0.007	0.001	0.001	0.004	0.007	0.005	0.0005	0.0001
C	35	I	765.-	-9.000	-9.00	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.107	0.034	0.017	0.027	0.002	0.023	0.0005	0.0008
C	36	I	487.	0.098	4.01	6.27	2.00	0.14	0.270	0.18	-9.00	0.02	-9.00	-9.00	0.07	-0.500	0.048	0.027	0.013	0.016	0.118	0.0015	0.0004
790822																							
W	5		2278.	0.091	4.04	6.16	4.15	0.50	0.180	0.14	0.21	0.06	0.03	0.05	0.02	0.036	0.002	0.001	0.011	0.002	0.017	0.0005	0.0001
W	7	I	440.-	-9.000	-9.00	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.082	0.065	0.029	0.018	0.046	0.014	0.0005	0.0006
W	16		1265.	0.091	4.04	7.60	5.25	0.62	0.240	0.18	0.33	0.06	0.01	0.05	0.02	0.035	0.006	0.002	0.014	0.010	0.016	0.0005	0.0002
W	19		2128.	0.105	3.98	6.30	5.10	0.21	0.220	0.39	0.36	0.06	0.02	0.01	0.22	0.045	0.001	0.001	0.007	0.008	0.015	0.0005	0.0001
W	23		1969.	0.087	4.06	5.83	4.70	0.24	0.160	0.57	0.43	0.07	0.01	0.01	0.15	0.076	0.002	0.001	0.007	0.009	0.048	0.0005	0.0001

INCO & FALBG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	SO4	NH4	CL	CA	HG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD	
W 24 I	263.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.065	0.018	0.006	0.015	0.002	0.035	0.0005	0.0002	
W 28	2020.	0.087	4.06	5.54	3.25	0.52	0.150	0.14	0.33	0.05	0.02	0.02	0.01	0.026	0.002	0.001	0.005	0.008	0.012	0.0005	0.0001
W 29	607.	0.100	4.00	6.45	4.55	0.77	0.170	0.21	0.93	0.13	0.01	0.06	0.03	0.070	0.001	0.001	0.007	0.005	0.049	0.0005	0.0001
W 34	661.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.011	0.002	0.001	0.010	0.012	0.005	0.0005	0.0002	
W 36 I	1121.	0.051	4.29	-9.00	7.90	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.000	0.173	0.042	-9.000	-9.000	-9.000	-9.000	0.0000	
W 37	1618.	0.095	4.02	5.69	3.45	0.50	0.170	0.46	0.58	0.08	0.05	0.02	0.04	0.129	0.002	0.001	0.007	0.010	0.096	0.0005	0.0001
790823																					
W 2	3688.	0.048	4.32	-9.00	4.70	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.000	0.001	0.001	-9.000	-9.000	-9.000	-9.000	0.0000	
W 4	1966.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.006	0.001	0.001	0.011	0.002	0.005	0.0005	0.0001	
W 5	1955.	0.091	4.04	6.16	6.05	0.72	0.780	0.15	0.71	0.04	0.03	0.09	0.02	0.021	0.007	0.001	0.017	0.005	0.007	0.0005	0.0002
W 7 N	2286.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.004	0.068	0.033	0.020	0.018	0.018	0.0005	0.0004	
W 16	2921.	0.112	3.95	9.74	6.80	0.92	0.670	0.15	0.25	0.01	0.01	0.05	0.03	0.019	0.002	0.001	0.016	0.011	0.009	0.0005	0.0001
W 19	1773.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.021	0.002	0.001	0.016	0.002	0.008	0.0005	0.0001	
W 22 I	1492.	0.148	3.83	13.32	9.50	0.99	0.670	0.20	0.17	0.02	0.01	0.03	0.04	0.024	0.002	0.001	0.023	0.002	0.012	0.0005	0.0003
W 23	1546.	0.105	3.98	9.21	6.10	0.72	0.430	0.12	0.27	0.03	0.01	0.02	0.02	0.012	0.001	0.001	0.014	0.002	0.003	0.0005	0.0001
W 24 N	858.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.018	0.001	0.001	0.018	0.002	0.008	0.0023	0.0005	0.0006
W 26 X	-9.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.026	0.002	0.001	0.019	0.004	0.007	0.0005	0.0001	
W 29 I	662.	0.191	3.72	16.93	11.75	1.58	0.900	0.32	0.34	-9.00	0.01	0.03	0.00	0.035	0.001	0.001	0.023	0.012	0.040	0.0005	0.0001
W 34	2382.	0.093	4.03	6.78	5.75	0.54	0.520	0.77	0.18	0.02	0.23	0.20	0.12	0.013	0.002	0.001	0.012	0.016	0.006	0.0005	0.0002
W 35 F	2765.	-9.000	-9.00	-9.00	-9.00	-9.000	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	0.039	0.002	0.001	0.016	0.002	0.016	0.0005	0.0001	
W 36 N	2254.	0.107	3.97	11.05	8.30	0.70	0.490	0.18	0.14	0.02	0.04	0.03	0.05	0.133	0.115	0.043	0.037	0.006	0.013	0.0005	0.0002
790827																					
C 2 N	706.	0.046	4.34	4.08	4.15	0.40	0.540	0.26	0.33	0.04	0.11	0.09	0.02	0.048	0.001	0.001	0.017	0.004	0.027	0.0005	0.0001
C 5	614.	0.059	4.23	4.70	5.40	0.38	0.820	0.12	0.36	0.05	0.06	0.10	0.02	0.099	0.016	0.004	0.018	0.014	0.072	0.0005	0.0003

INCO & FALRG OPERATING PERIOD SELECTED EVENTS

F ST P	WOL	WF	PM	ACIO	SO4	NO3	MM4	CL	CA	MS	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CO
C 7 I	1361.	0.062	4.21	4.76	4.40	0.35	0.430	0.09	0.31	0.06	0.01	0.26	0.02	0.055	0.035	0.014	0.009	0.008	0.025	0.0005	0.0002
C 16 *	683.	0.089	4.05	7.52	6.65	0.39	0.470	0.11	0.31	0.04	0.00	0.07	0.03	0.063	0.039	0.009	0.021	0.024	0.027	0.0005	0.0007
C 17 M	577.	0.072	4.14	6.74	5.65	0.51	0.620	0.12	0.32	0.03	0.01	0.03	0.04	0.025	0.006	0.001	0.014	0.002	0.011	0.0005	0.0001
C 18 M	935.	0.074	4.13	7.67	6.70	0.36	0.580	0.24	0.42	0.04	0.28	0.10	0.00	0.083	0.268	0.176	0.079	0.008	0.020	0.0005	0.0029
C 22 N	787.	0.045	4.35	4.67	3.90	0.29	0.430	0.15	0.24	0.04	0.04	0.10	0.02	0.240	0.026	0.019	0.016	0.002	0.096	0.0015	0.0001
C 23 M	821.	0.035	4.46	5.73	6.20	0.36	0.760	0.26	0.33	0.08	0.09	0.09	0.03	0.144	0.290	0.158	0.054	0.008	0.063	0.0005	0.0019
C 24	490.	0.026	4.50	2.75	2.15	0.21	0.230	0.36	0.30	0.06	0.12	0.24	0.01	0.026	0.003	0.001	0.006	0.015	0.022	0.0005	0.0001
C 26 *	913.	0.105	3.98	8.13	6.80	0.37	0.460	0.17	0.21	0.01	0.03	0.01	0.07	0.083	0.068	0.043	0.036	0.017	0.036	0.0005	0.0013
C 29 M	590.	0.055	4.26	5.14	3.80	0.39	0.400	0.12	0.40	0.06	0.07	0.04	0.21	0.024	0.003	0.002	0.010	0.005	0.014	0.0005	0.0002
C 34 X	465.	0.098	4.01	5.78	5.65	0.41	0.650	0.48	0.58	0.08	0.07	0.10	0.12	-0.144	0.008	0.001	0.014	0.010	0.134	0.0005	0.0003
C 36 N	1353.	0.030	4.42	4.24	3.30	0.29	0.360	0.09	0.21	0.04	0.05	0.04	0.02	0.064	0.012	0.007	0.015	0.002	0.026	0.0005	0.0001
C 37 N	557.	0.062	4.21	6.43	5.40	0.46	0.640	0.23	0.30	0.04	0.04	0.05	0.03	0.071	0.063	0.025	0.027	0.004	0.046	0.0005	0.0003
790829																					
M 4	807.	0.078	4.11	6.36	4.60	0.59	0.470	0.15	0.16	0.08	0.02	0.05	0.03	0.015	0.001	0.001	0.009	0.005	0.022	0.0005	0.0001
M 5 I	721.	0.091	4.04	6.78	6.15	0.73	0.880	0.20	0.34	0.05	0.03	0.06	0.02	0.035	0.006	0.001	0.014	0.029	0.023	0.0005	0.0002
M 17	2567.	0.069	4.16	5.21	3.90	0.41	0.380	0.08	0.38	0.02	0.01	0.01	0.02	0.002	0.001	0.001	0.009	0.006	0.005	0.0005	0.0001
M 19 I	2066.	0.100	4.00	7.27	6.20	0.81	0.800	0.18	0.36	0.04	0.02	0.03	0.03	0.032	0.019	0.006	0.019	0.013	0.012	0.0005	0.0004
M 22	3026.	0.056	4.25	4.51	3.25	0.27	0.320	0.06	0.11	0.01	0.01	0.01	0.02	0.003	0.001	0.001	0.008	0.009	0.005	0.0005	0.0001
M 23	2194.	0.072	4.14	5.57	3.95	0.46	0.430	0.20	0.26	0.02	0.01	0.02	0.02	0.003	0.007	0.003	0.010	0.011	0.005	0.0005	0.0001
M 24	1362.	0.091	4.04	7.33	5.35	0.63	0.580	0.20	0.22	0.02	0.01	0.01	0.03	0.021	0.003	0.001	0.012	0.011	0.010	0.0005	0.0001
M 26 I	940.	0.074	4.13	6.39	4.95	0.37	0.320	0.09	0.10	0.02	0.02	0.03	0.02	0.065	0.022	0.007	0.015	0.023	0.011	0.0005	0.0005
M 28	2169.	0.046	4.34	4.41	5.20	0.62	1.250	0.30	0.27	0.04	0.01	0.34	0.02	0.002	0.002	0.002	0.010	0.013	0.005	0.0005	0.0001
M 29	2463.	0.069	4.16	5.61	4.35	0.42	0.500	0.08	0.17	0.01	0.01	0.01	0.03	0.016	0.001	0.001	0.012	0.008	0.005	0.0005	0.0001

INCO & FALRG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	MF	PH	AC10	S04	M03	M04	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CD
M 35 I	892.	0.087	4.06	5.94	4.70	0.150	0.420	0.11	0.11	0.01	0.01	0.02	0.02	0.039	0.027	0.005	0.010	0.017	0.009	0.0005	0.0002
M 36 I	3708.	0.069	4.16	4.55	3.20	0.29	0.280	0.02	0.16	0.01	0.02	0.01	0.12	0.025	0.035	0.014	0.012	0.005	0.005	0.0005	0.0003
M 37	1864.	0.091	4.04	6.84	5.30	0.63	0.610	0.25	0.30	0.03	0.01	0.01	0.03	0.018	0.002	0.001	0.012	0.024	0.005	0.0005	0.0001
790910																					
C 7	605.	0.026	4.59	2.84	1.90	0.28	0.340	0.01	0.17	0.03	0.02	0.06	0.01	0.010	0.001	0.001	0.006	0.004	0.005	0.0005	0.0001
C 16 F	2652.	0.034	4.47	3.17	2.10	0.35	0.260	0.06	0.20	0.03	0.01	0.02	0.01	0.070	0.001	0.001	0.009	0.006	0.001	0.0005	0.0001
C 17	2333.	0.030	4.53	3.42	2.35	0.45	0.400	0.08	0.38	0.06	0.05	0.01	0.02	0.040	0.001	0.001	0.007	0.004	0.034	0.0005	0.0002
C 19 I	1158.	0.041	4.39	4.10	3.30	0.36	0.590	0.08	0.19	0.02	0.04	0.02	0.02	0.052	0.034	0.007	0.018	0.008	0.012	0.0005	0.00027
C 22	992.	0.022	4.66	3.38	2.10	0.33	0.380	0.10	0.24	0.02	0.06	0.05	0.01	0.043	0.002	0.002	0.009	0.005	0.066	0.0005	0.0001
C 23 I	1080.	0.034	4.47	4.03	4.15	0.34	0.880	0.09	0.24	0.02	0.05	0.03	0.01	0.088	0.035	0.021	0.010	0.004	0.007	0.0005	0.0003
C 24	517.	0.029	4.54	2.82	2.00	0.32	0.430	0.08	0.14	0.02	0.05	0.04	0.00	0.022	0.002	0.001	0.008	0.003	0.005	0.0005	0.0001
C 25	827.	0.001	6.27	4.00	1.90	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000
C 28 I	1243.	0.022	4.56	2.68	2.70	0.29	0.590	0.05	0.19	0.02	0.04	0.01	0.01	0.057	0.050	0.008	0.010	0.005	0.007	0.0005	0.0003
C 34 *	1764.	0.028	4.56	2.82	2.40	0.27	0.490	0.09	0.11	0.02	0.06	0.04	0.00	0.019	0.001	0.001	0.009	0.003	0.009	0.0005	0.0001
C 36	877.	0.020	4.69	2.65	1.85	0.23	0.320	0.20	0.19	0.02	0.14	0.08	0.01	0.024	0.002	0.004	0.008	0.040	0.012	0.0010	0.0003
C 37	1311.	0.023	4.64	2.87	1.85	0.28	0.290	0.08	0.37	0.02	0.03	0.34	0.01	0.015	0.001	0.001	0.006	0.006	0.007	0.0005	0.0001
791011																					
C 2	2319.	0.069	4.16	4.96	1.70	0.82	0.252	0.06	0.11	0.02	0.01	0.01	0.01	0.019	0.001	0.001	0.018	0.002	0.007	0.0005	0.0001
C 5	1291.	0.063	4.20	5.81	1.90	0.95	0.275	0.29	0.21	0.03	0.05	0.14	0.02	0.023	0.002	0.001	0.015	0.048	0.005	0.0005	0.0001
C 19	2035.	0.048	4.32	4.93	1.65	0.75	0.242	0.06	0.10	0.02	0.03	0.03	0.01	0.041	0.005	0.003	0.016	0.017	0.017	0.0025	0.0002
C 21 M	958.	0.076	4.12	5.89	2.15	0.97	0.264	0.10	0.22	0.03	0.01	0.05	0.02	0.037	0.012	0.005	0.019	0.002	0.020	0.0005	0.0003
C 23	2856.	0.042	4.38	3.75	1.75	0.58	0.188	0.17	0.45	0.08	0.02	0.04	0.01	0.022	0.009	0.005	0.014	0.002	0.009	0.0005	0.0001
C 24 I	2314.	0.045	4.35	4.05	1.95	0.41	0.237	0.11	0.10	0.02	0.10	0.06	0.01	0.024	0.012	0.010	0.012	0.002	0.015	0.0005	0.0001
C 25 I	2654.	0.058	4.24	5.51	4.70	0.46	0.730	0.05	0.09	0.04	0.04	0.12	0.01	0.081	0.065	0.057	0.035	0.002	0.005	0.0015	0.0002

INCO & FALRG OPERATING PERIOD SELECTED EVENTS

F ST P	VOL	HF	PH	ACID	SO4	NO3	NH4	CL	CA	MG	NA	K	F	FE	CU	NI	PB	ZN	AL	CR	CO
C 26	869.	0.062	4.21	5.53	1.95	0.80	0.220	0.09	0.12	0.02	0.02	0.02	0.01	0.034	0.010	0.002	0.019	0.001	0.016	0.0005	0.0003
C 28	3529.	0.048	4.32	3.95	1.35	0.50	0.178	0.01	0.05	0.01	0.01	0.01	0.01	0.010	0.002	0.001	0.011	0.002	0.005	0.0005	0.0001
C 36 I	2755.	0.049	4.31	4.13	1.55	0.52	0.184	0.03	0.09	0.02	0.02	0.02	0.01	0.028	0.012	0.004	0.012	0.002	0.005	0.0005	0.0002
C 37	4437.	0.040	4.40	3.62	1.35	0.40	0.153	0.01	0.03	0.01	0.01	0.01	0.01	0.008	0.001	0.001	0.010	0.002	0.005	0.0005	0.0001

APPENDIX 3

Meteorological Summary

Appendix 3
Meteorological Summary

Event No.	Date of Event	Starting Time (LST)	Ending Time (LST)	Duration (Hours)	Precipitation Type*	Precipitation Amount (mm)	Front*	Surface Wind Direction (degrees)	Upper Wind Direction (degrees)	Plume Direction (degrees)	Sector Width (degrees)
1	27-28 Aug. 78	2400	0800	8	R	13	W	110-180	150-190	130-190	60
2-1	28-29 Aug. 78	0800	1400	6	TR			160-190	200-240	160-250	90
2-2	28-29 Aug. 78	1900	2100	2	RW	7	C	330-340	290-310	230-340	60
3	29-30 Aug. 78	1300	1800	1	TRW	5	C	290-330	270-280	230-340	60
4-1	02-03 Sept. 78	1500	1900	4	TRW			210-290	220-270		
4-2	02-03 Sept. 78	2200	2800	2	TRW	19	C	200-260	220-250	200-290	90
5-1	06-07 Sept. 78	1200	1700	5	RW			230-270	240-260		
5-2	06-07 Sept. 78	2000	2100	1	RW-			270-320	280-300	230-300	70
5-3	06-07 Sept. 78	0600	0700	1	RW-	7	W	360-030	340-350	340-60	80
6-1	09-10 Sept. 78	1800	1900	1	RW-			80-100	170-190		
6-2	09-10 Sept. 78	0100	0500	4	TRW	3	W	110-150	140-160	130-190	60
7-1	10-11 Sept. 78	0800	1100	3	R-			150-160	170-200		
7-2	10-11 Sept. 78	0400	0530	1	R	4	W	160-190	190-260	200-260	60

*R: rain RW: rain shower T: thunderstorm
 *H: heavy -> light -> very light
 *W: warm front C: cold front

Event No.	Date of Event	Starting Time (LST)	Ending Time (LST)	Duration (Hours)	Precipitation Type*	Precipitation Amount (mm)	Front*	Surface Wind Direction (degrees)	Upper Wind Direction (degrees)	Plume Direction (degrees)	Sector Width (degrees)
8	11-12 Sept. 78	1900	2100	2	RW	2	C	270-030	340-350	270-350	80
9	14-15 Sept. 78	1300	2300	10	TRW	16	W	130-170	150-180	130-180	50
10	15-16 Sept. 78	1700	1900	2	RW-	5	C	240-260	250-270	250-300	50
11-1	09-10 June 79	0800	0000	16	RW-			50-130	40-80		
11-2	09-10 June 79	0700	0800	1	RW	10	W	170-190	210-220	50-180	130
12	21-22 June 79	2000	2300	3	RW	2	W	200-180	200-220	150-240	90
13	23-24 June 79	1300	1900	6	RW-	1	C	330-360	300-320	250-360	70
14	26-27 June 79	1600	0200	10	TRW-	13	W	180-360	160-230	220-330	110
15-1	30-31 June 79	0900	1200	3	R-			30-40	10-30		
15-2	30-31 June 79	2100	0800	11	R+	12	W	20-70	10-50	360-80	80
16-1	01-02 July 79	0800	2000	12	RW+			40-90	340-350		
16-2	01-02 July 79	2200	2300	1	RW	14	C	20-360	330-340	330-90	120

*: R: rain, RW: rain shower, T: thunderstorm
 +: heavy, -: light, --: very light
 W: warm front, C: cold front

Event No.	Date of Event	Starting Time (LST)	Ending Time (LST)	Duration (Hours)	Precipitation Type*	Precipitation Amount (mm)	Front*	Surface Wind Direction (degrees)	Upper Wind Direction (degrees)	Plume Direction (degrees)	Sector Width (degrees)
17	24-25 July 79	0400	0800	4	RW+	11	W	170-180	200-220	150-240	90
18	25-26 July 79	0800	0500	21	TRW+	17	C	180-240 360-30	260-230 330-330	150-240 360-30	90 80
19	28-29 July 79	1000	1100	1	RW	4	W	210-240	240-260	200-260	60
20	01-02 Aug. 79	0400	0800	4	RW	8	C	40-70	-	40-160	120
21	02-03 Aug. 79	0800	1500	7	RW	7	C	340-40	270-350	270-50	140
22	06-07 Aug. 79	0500	0800	3	TRW	13	C	190-210	180-210	150-210	60
23	09-10 Aug. 79	0300	0700	4	RW-	5	C	190-200	200-150	150-210	90
24	17-18 Aug. 79	1400	2100	7	RW-	9	W	210-180	200-230	160-230	70
25	20-21 Aug. 79	1300	2100	8	TRW	8	C	220-310	170-10	160-20	220
26	22-23 Aug. 79	0200	0700	5	R	9	W	100-150	150-200	100-200	100

* = R: rain, RW: rain shower, T: thunderstorm
 +: heavy, -: light, --: very light
 W: warm front, C: cold front

Event No.	Date of Event	Starting Time (LST)	Ending Time (LST)	Duration (Hours)	Precipitation Type ^a	Precipitation Amount (mm)	Front ^b	Surface Wind Direction (degrees)	Upper Wind Direction (degrees)	Plume Direction (degrees)	Sector Width (degrees)
27-1	23-24 Aug. 79	2200	2400	2	TRW			120-140	130-180		
27-2	23-24 Aug. 79	0500	0600	1	RW ⁺	14	W	130-160	130-180	70-180	110
28	27-28 Aug. 79	1600	2300	7	R-	6	C	260-40	220-340	150-80	250
29-1	29-30 Aug. 79	0800	1400	6	RW ⁺			170-220	210-220	160-310	150
29-2	29-30 Aug. 79	0200	0400	2	RW-	14	W	180-210	-		
30	10-11 Sept. 79	0800	1100	3	RW	9	C	270-290	260-320	270-10	100
31	11-12 Oct. 79	2200	0800	10	R-	15	C	100-130	140-160	100-210	110

^a R: rain, RW: rain shower, T: thunderstorm
⁺: heavy, -: light, --: very light
^b W: warm front, C: cold front

APPENDIX 4

Stratified Precipitation Data

Concentration data are grouped according to sampling date and frontal passage. The symbol at the top left corner of each table corresponds to the parameter under consideration. W and C under the heading F (for fronts) designate warm and cold frontal passages. The event dates are given in column 2. BN and PN indicate the number of samples collected outside and inside the plume for each individual event. The rest of the data are given in three blocks, i.e. "BACK" for background, "PLUM" for plume sector and "EXSS" for additional concentration due to plume interaction with precipitation. In each block, "MEAN", "STDV", "COV" and "MN DPO" correspond to mean concentration, standard deviation, coefficient of variation and mean deposition. Statistics for the background and plume sector blocks are based on BN and PN data points. A "-9.00" corresponds to data not determined.

The EXSS concentration is NOT calculated by subtracting the overall mean background concentration from the overall mean plume sector concentration. Rather, for each individual event, the mean background concentration is subtracted from the concentration of each sample within the plume sector and these differences are then averaged to obtain the mean additional plume sector concentration for the particular event. Negative values of additional concentration were replaced by zeros during individual events.

It should be noted that the concentrations of NO_3 and NH_4 are reported as N-NO_3 and N-NH_4 .

MF	HACK				PLUM				EASS									
	DATE	RM	PN	MEAN	STDV	COV	4N	DBO	MEAN	STDV	COV	4N	DBO	MEAN	STDV	COV	4N	DBO
C	780828	3	4	0.0437	0.0369	0.8449	0.1914		0.0489	0.0048	0.0975	0.3138		0.0053	0.0048	0.9078	0.0300	
C	780829	5	3	0.0220	0.0094	0.4279	0.1835		0.0485	0.0304	0.6278	0.1460		0.0312	0.0243	0.7795	0.0973	
C	780811	0	3	0.0000	0.0000	0.0000	0.0000		0.0286	0.0172	0.1746	0.2610		0.0000	0.0000	0.0000	0.0000	
C	780915	2	1	0.0207	0.0007	0.0345	0.0264		0.0562	0.0000	0.0000	0.1255		0.0356	0.0000	0.0000	0.0794	
C	790623	2	3	0.0046	0.0037	0.4305	0.0045		0.0290	0.0127	0.4389	0.0178		0.0204	0.0127	0.6235	0.0120	
C	790701	3	1	0.0640	0.0097	0.2108	0.8228		0.0955	0.0000	0.0000	2.6267		0.0495	0.0000	0.0000	1.3613	
C	790725	3	10	0.0337	0.0044	0.1301	0.6446		0.0770	0.0235	0.3047	1.4147		0.0433	0.0235	0.5414	0.8156	
C	790801	2	6	0.0144	0.0020	0.1032	0.1824		0.0359	0.0110	0.3065	0.1942		0.0165	0.0110	0.6659	0.0808	
C	790802	3	8	0.0355	0.0059	0.1863	0.1208		0.0293	0.0110	0.3742	0.2388		0.0030	0.0051	1.7345	0.0183	
C	790806	5	2	0.0164	0.0094	0.5734	0.2335		0.0390	0.0186	0.4762	0.5101		0.0226	0.0186	0.8217	0.2851	
C	790809	8	3	0.0257	0.0070	0.2735	0.1177		0.0233	0.0062	0.2673	0.0897		0.0013	0.0018	1.3954	0.0068	
C	790820	2	5	0.0331	0.0015	0.0660	0.3130		0.1307	0.0384	0.2767	1.0712		0.1055	0.0384	0.3636	0.7714	
C	790827	1	9	0.0257	0.0000	0.0000	0.0893		0.0542	0.0135	0.2496	0.3231		0.0285	0.0135	0.4746	0.1671	
C	790910	7	3	0.0214	0.0091	0.4244	0.1715		0.0322	0.0078	0.2423	0.2621		0.0108	0.0078	0.7240	0.0862	
C	791011	7	4	0.0531	0.0106	0.2008	0.8682		0.0568	0.0120	0.2107	0.8214		0.0068	0.0094	1.3771	0.0600	
		MEAN		0.0249	0.0085	0.2974	0.2835		0.0575	0.0159	0.3113	0.5611		0.0272	0.0142	0.8674	0.2771	
		STDV		0.0120	0.0082	0.2252	0.2730		0.0311	0.0094	0.1341	0.6704		0.0262	0.0100	0.6018	0.3050	
		COV		0.0162	1.0404	0.7572	0.9028		0.5402	0.5892	0.4308	1.1948		0.9633	0.6999	0.4632	1.4253	
		NN		14.0000	13.0000	13.0000	14.0000		15.0000	13.0000	13.0000	15.0000		14.0000	12.0000	12.0000	14.0000	

PH	HACK						PLUM						EXSS					
	DATE	BU	DA	STDV	COV	MIN DEP	MEAN	STDV	COV	MIN DEP	MEAN	STDV	COV	MIN DEP	MEAN	STDV	COV	MIN DEP
F																		
W	780827	5	0	4.0846	0.2835	0.0718	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780902	4	1	4.2025	0.0031	0.0194	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780906	2	3	4.6910	0.3600	0.0802	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780909	2	1	4.1951	0.0650	0.0203	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780910	4	3	4.2600	0.2331	0.0547	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780914	7	0	3.3825	0.0361	0.0261	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780909	9	1	4.0892	0.0460	0.0235	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780921	6	2	4.4250	0.1560	0.0357	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780925	3	4	4.1767	0.0369	0.0088	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780930	6	1	3.9700	0.1536	0.0387	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780924	10	4	4.1820	0.0740	0.0177	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780928	2	0	4.2350	0.0450	0.0106	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780917	5	2	3.4400	0.0770	0.0195	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780922	7	1	4.0245	0.0284	0.0071	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780923	5	3	4.0440	0.1322	0.0325	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780929	8	5	4.1550	0.0450	0.0224	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
MEAN				4.1554	0.1280	0.0305	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
STDV				0.1477	0.0407	0.0208	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
COV				0.0355	0.7046	0.6421	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
MIN				15.0000	15.0000	15.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000

PM							BACK							PLUM							EXSS						
F	DATE	BN	BN	MEAN	STDV	COV	MN	DPD	MEAN	STDV	COV	MN	DPD	MEAN	STDV	COV	MN	DPD	MEAN	STDV	COV	MN	DPD				
C	790829	3	4	4.5200	0.3692	0.0817	-9.0000		4.3125	0.0413	0.0096	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790829	5	3	4.7080	0.2219	0.0471	-9.0000		4.4800	0.4433	0.0989	-9.0000		0.1307	0.1848	1.4142	-9.0000		0.1307	0.1848	1.4142	-9.0000					
C	790911	0	3	-9.0000	-9.0000	-9.0000	-9.0000		4.0131	0.0793	0.0194	-9.0000		-9.0000	-9.0000	-9.0000	-9.0000		-9.0000	-9.0000	-9.0000	-9.0000					
C	790915	2	1	4.6850	0.0151	0.0032	-9.0000		4.2500	-9.0000	-9.0000	-9.0000		0.0	-9.0000	-9.0000	-9.0000		0.0	-9.0000	-9.0000	-9.0000					
C	790923	2	3	5.1100	0.2000	0.0391	-9.0000		4.5900	0.2276	0.0496	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790701	3	1	4.3467	0.0403	0.0204	-9.0000		4.0200	-9.0000	-9.0000	-9.0000		0.0	-9.0000	-9.0000	-9.0000		0.0	-9.0000	-9.0000	-9.0000					
C	790725	3	10	4.4767	0.0574	0.0128	-9.0000		4.1320	0.1248	0.0302	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790801	2	6	4.7150	0.0450	0.0096	-9.0000		4.4633	0.1241	0.0278	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790802	3	8	4.4567	0.0757	0.0170	-9.0000		4.5612	0.1537	0.0337	-9.0000		0.1375	0.1062	0.7721	-9.0000		0.1375	0.1062	0.7721	-9.0000					
C	790804	5	2	4.9820	0.3206	0.0657	-9.0000		4.4650	0.2250	0.0504	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790809	8	3	4.6027	0.1303	0.0263	-9.0000		4.6500	0.1296	0.0279	-9.0000		0.0738	0.1043	1.4142	-9.0000		0.0738	0.1043	1.4142	-9.0000					
C	790820	2	5	4.4400	0.0199	0.0044	-9.0000		3.8740	0.1167	0.0301	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790827	1	9	4.5900	-9.0000	-9.0000	-9.0000		4.2800	0.1121	0.0262	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	790910	7	3	4.9457	0.5841	0.1205	-9.0000		4.5067	0.1133	0.0251	-9.0000		0.0	0.0	-9.0000	-9.0000		0.0	0.0	-9.0000	-9.0000					
C	791011	7	4	4.2843	0.0473	0.0204	-9.0000		4.2550	0.0874	0.0205	-9.0000		0.0229	0.0269	1.1759	-9.0000		0.0229	0.0269	1.1759	-9.0000					

		MEAN		4.6220	0.1705	0.0362	-9.0000		4.3235	0.1522	0.0346	-9.0000		0.0261	0.0352	1.1942	-9.0000		0.0261	0.0352	1.1942	-9.0000					
		STDV		0.2148	0.1607	0.0333	-9.0000		0.2268	0.0976	0.0214	-9.0000		0.0481	0.0593	0.2621	-9.0000		0.0481	0.0593	0.2621	-9.0000					
		COV		0.9465	0.9426	0.9709	-9.0000		0.0525	0.6416	0.6182	-9.0000		1.8474	1.6851	0.2196	-9.0000		1.8474	1.6851	0.2196	-9.0000					
		NN		14.0000	13.0000	13.0000	0.0		15.0000	13.0000	13.0000	0.0		14.0000	12.0000	4.0000	0.0		14.0000	12.0000	4.0000	0.0					

ACID																			
F	DATE	BU	BN	BACs		STUD	CLV	MM DPO	PLUM		STDV	COV	MM DPO	EXSS		STDV	COV	MM DPO	
				LEN	TH				MEAN	STDV				MEAN	STDV				
W	780827	5	0	7.4160	1.4855	0.1877	104.1752		-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	
W	780902	4	1	3.4775	0.4620	0.2469	83.1107		4.2400	-9.0000	-9.0000	0.0000	136.5754	0.2625	-9.0000	-9.0000	0.0000	8.4554	
W	780906	2	1	4.9253	1.1450	0.2325	64.6683		5.0733	0.8854	0.1704	29.7024		0.4550	0.6435	1.4142	2.0709		
W	780909	2	1	4.0100	0.2900	0.0466	29.6791		7.9800	-9.0000	-9.0000	46.3756		1.9700	-9.0000	-9.0000	11.4486		
W	780910	4	3	5.1525	1.4041	0.1117	24.3879		11.6800	2.5734	0.2203	45.3754		6.5275	2.5734	0.3942	25.1804		
W	780914	7	6	4.3547	0.4711	0.0393	104.6292		-9.0000	-9.0000	-9.0000	-9.0000		-9.0000	-9.0000	-9.0000	-9.0000		
W	790609	8	1	9.4175	1.0180	0.1129	81.6955		8.7000	-9.0000	-9.0000	71.8937		0.0	-9.0000	-9.0000	0.0		
W	790621	4	0	5.0450	0.8812	0.1747	12.8982		-9.0000	-9.0000	-9.0000	-9.0000		-9.0000	-9.0000	-9.0000	-9.0000		
W	790626	1	4	5.1000	0.6634	0.1146	125.4560		8.2425	1.5574	0.1889	65.0894		2.4125	1.5573	0.6455	17.4909		
W	790630	4	1	9.0423	1.5739	0.1739	115.5213		11.1300	-9.0000	-9.0000	174.7985		2.0817	-9.0000	-9.0000	32.6931		
W	790724	10	4	5.6630	0.4094	0.1381	62.2862		6.0900	0.5571	0.0915	65.4509		0.3410	0.4408	1.2926	2.7984		
W	790728	2	0	4.1554	0.6550	0.1064	44.2416		-9.0000	-9.0000	-9.0000	-9.0000		-9.0000	-9.0000	-9.0000	-9.0000		
W	790817	5	2	4.6740	1.1243	0.1134	66.2856		11.0500	1.2400	0.1122	113.3671		1.2070	1.2070	1.0000	11.2403		
W	790822	7	0	4.2243	0.4395	0.1027	73.7516		-9.0000	-9.0000	-9.0000	-9.0000		-9.0000	-9.0000	-9.0000	-9.0000		
W	790823	4	1	4.5245	1.1200	0.1143	133.2085		13.7667	2.4212	0.1759	132.2650		5.2442	2.4212	0.4617	43.5167		
W	790829	8	5	5.1550	0.9822	0.1707	80.6014		6.1860	0.9281	0.1500	68.1568		0.6720	0.5523	0.8219	6.5641		

MEAN				6.6230	0.9776	0.1540	76.3672		8.5580	1.4489	0.1585	86.2727		1.9248	1.3422	0.8615	16.6789		
STDV				1.6722	0.3546	0.0667	34.1845		2.9024	0.7243	0.0412	43.7996		2.0380	0.8167	0.3659	13.1995		
COV				0.2522	0.3627	0.4200	0.4477		0.3391	0.4999	0.2602	0.5077		1.0588	0.6085	0.4247	0.8992		
MM				15.0000	16.0000	16.0000	16.0000		11.0000	7.0000	7.0000	11.0000		11.0000	7.0000	7.0000	11.0000		

ACID										MACK				PLUM				EXSS			
F	DATE	BU	PN	MEAN	STDV	COV	MIN	MAX	DPO	MEAN	STDV	COV	MIN	MAX	DPO	MEAN	STDV	COV	MIN	MAX	DPO
C	780828	3	3	3.0100	0.7083	0.2353	16.9825			2.3367	1.4178	0.6068	19.4111			0.4367	0.6175	1.4142	3.5662		
C	780829	5	1	2.3320	1.3985	0.6023	20.1380			5.2700	9.0000	9.0000	20.5422			2.9480	9.0000	9.0000	11.4911		
C	780911	0	3	9.0000	9.0000	9.0000	9.0000			6.9067	2.4111	0.3491	18.2091			9.0000	9.0000	9.0000	9.0000		
C	780915	0	0	9.0000	9.0000	9.0000	9.0000			9.0000	9.0000	9.0000	9.0000			9.0000	9.0000	9.0000	9.0000		
C	780923	0	0	9.0000	9.0000	9.0000	9.0000			9.0000	9.0000	9.0000	9.0000			9.0000	9.0000	9.0000	9.0000		
C	780924	3	1	4.3267	0.4623	0.0378	86.9027			6.2500	9.0000	9.0000	171.9082			1.5233	9.0000	9.0000	41.8997		
C	780925	3	10	3.2133	0.3587	0.1116	65.4344			6.3800	1.2701	0.1991	119.1561			3.1667	1.2701	0.4011	61.9606		
C	780926	2	4	2.9600	0.2300	0.0865	24.9129			3.6575	0.5855	0.1601	23.3178			0.9975	0.5855	0.5869	6.1908		
C	780927	2	8	3.3100	0.1000	0.0302	13.1262			3.5337	0.8333	0.2358	29.2948			0.4513	0.6058	1.3425	2.9076		
C	780928	4	2	2.6150	0.3398	0.1299	36.4621			3.6100	0.7100	0.1967	48.5912			0.9950	0.7100	0.7136	12.7021		
C	780929	8	2	3.0375	0.4169	0.1373	14.2725			2.6950	0.1050	0.0390	14.1553			0.0	0.0	9.0000	0.0		
C	780930	2	3	3.6600	0.4200	0.1207	33.7018			8.2133	2.3636	0.2878	101.2133			6.7333	2.3636	0.4993	53.4651		
C	780931	1	9	2.7500	9.0000	9.0000	9.5500			5.5067	1.1545	0.2097	32.5876			2.7567	1.1545	0.4188	15.8979		
C	780932	6	3	2.9967	0.2939	0.0961	24.3262			3.6700	0.5593	0.1524	29.9552			0.7122	0.5044	0.7082	6.6548		
C	781011	7	6	6.6500	0.8155	0.1754	75.4809			4.8950	0.8166	0.1668	72.6718			0.5250	0.5419	1.0322	6.1488		
										MEAN											
										3.2309				0.5040				1.6038			
										0.7202				0.3419				1.3946			
										0.2229				0.4786				0.8696			
										12.0000				11.0000				12.0000			
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S04

BACK

PLUM

EXSS

F	DATE	BN	PN	MEAN	STDV	COV	MN	DPD	MEAN	STDV	COV	MN	DPD			
M	790827	5	0	3.9900	0.5142	0.1289	51.9257	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000			
M	790907	4	1	3.4375	0.5628	0.1637	60.0779	3.8500	-9.0000	-9.0000	0.4125	-9.0000	13.2871			
M	790906	2	3	2.8500	0.3500	0.1228	31.4868	5.4500	1.0108	0.1855	31.5161	2.5000	1.0108	0.3888	16.1454	
M	790909	2	1	5.4250	0.5250	0.0901	24.5453	9.1000	-9.0000	-9.0000	52.8845	3.2750	-9.0000	-9.0000	19.0326	
M	790910	4	3	4.0625	1.1701	0.2840	22.0136	10.0500	0.2273	0.0226	39.0845	5.9875	0.2274	0.0380	23.2012	
M	790914	7	0	4.2643	0.4545	0.1067	46.5502	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	
M	790809	8	2	7.0437	0.9036	0.1283	63.3373	8.4000	1.1500	0.1369	76.1490	1.3563	1.1500	0.8479	12.9749	
M	790621	6	2	3.9063	0.5334	0.1365	8.7193	8.5000	1.9000	0.2235	12.2580	4.5917	1.9000	0.4138	6.2750	
M	790624	3	4	5.3500	0.3895	0.0728	109.9255	8.6125	0.6339	0.0736	72.2197	3.2625	0.6338	0.1943	28.5601	
M	790630	6	1	6.7917	1.6991	0.2502	83.4222	8.5500	-9.0000	-9.0000	134.2792	1.7583	-9.0000	-9.0000	27.6150	
M	790724	11	4	3.6813	0.4002	0.1087	39.0554	4.3625	0.6484	0.1486	45.8005	0.6807	0.6484	0.9526	5.5054	
M	790728	2	1	5.5000	0.0	0.0	40.8649	11.8000	-9.0000	-9.0000	24.5032	6.3000	-9.0000	-9.0000	13.0822	
M	790817	5	2	5.4700	0.4906	0.0897	37.1106	7.0500	0.8500	0.1206	72.2664	1.5800	0.8500	0.5380	15.4925	
M	790822	7	1	4.3500	0.7167	0.1647	51.7474	7.9000	-9.0000	-9.0000	62.7633	3.5500	-9.0000	-9.0000	28.2038	
M	790823	5	3	5.8800	0.6431	0.1162	102.2636	9.8500	1.4301	0.1452	96.0564	3.9700	1.4300	0.3602	34.8256	
M	790829	8	5	4.4875	0.7167	0.1597	63.2379	5.0400	1.1034	0.2189	53.7977	0.8100	0.7315	0.9030	7.5989	
MEAN									7.7511	0.9949	0.1617	66.1136	2.8667	0.9535	0.5152	17.8616
STDV									2.2381	0.4601	0.0614	34.1482	1.8279	0.4652	0.3044	8.9167
COV									0.2887	0.4625	0.4332	0.5326	0.6376	0.4878	0.5909	0.4998
MN									16.0000	9.0000	9.0000	16.0000	16.0000	9.0000	9.0000	16.0000

504

S04										BACK				PLUM				EXSS			
F	DATE	BU	DN	MEAN	STDV	COV	NN.DPN	MEAN	STDV	COV	NN.DPN	MEAN	STDV	COV	NN.DPN	MEAN	STDV	COV	NN.DPN		
C	790828	3	4	2.0167	0.7771	0.3853	11.1351	2.2500	0.7425	0.3300	12.3080	0.4167	0.5947	1.4272	0.8254						
C	790829	5	2	0.7900	0.3392	0.4281	6.8458	4.9250	0.4750	0.0964	13.4759	4.1350	0.4750	0.1149	11.2335						
C	790831	0	3	0.0000	0.0000	0.0000	0.0000	0.0000	0.2966	0.0736	10.6780	0.0000	0.0000	0.0000	0.0000						
C	790915	2	1	0.9750	0.3750	0.3846	1.2571	3.0000	0.0000	0.0000	6.6974	2.0250	0.0000	0.0000	4.5207						
C	790823	3	3	0.5500	0.1780	0.3236	0.4132	2.3500	0.7483	0.3184	1.4688	1.8000	0.7483	0.4157	1.0985						
C	790701	3	1	2.1500	0.0817	0.0380	39.3347	3.8000	0.0000	0.0000	104.5202	1.6500	0.0000	0.0000	45.3838						
C	790725	3	10	1.4500	0.5657	0.3058	47.1298	4.1050	1.1354	0.2766	76.0176	2.2550	1.1354	0.5035	43.0887						
C	790801	2	6	1.1500	0.1500	0.1304	10.1059	1.9333	0.5249	0.2715	9.9779	0.7833	0.5249	0.6701	3.7267						
C	790802	4	8	1.2625	0.3224	0.2557	3.9076	2.0937	0.8543	0.4083	16.4088	0.9141	0.7290	0.7976	6.5988						
C	790806	6	2	1.0167	0.1724	0.1696	13.9377	2.4250	0.3750	0.1546	32.7778	1.4083	0.3750	0.2663	18.8247						
C	790809	8	3	1.0750	0.2062	0.1918	5.3482	1.5833	0.6637	0.4192	5.1115	0.5500	0.6255	1.1373	1.0622						
C	790820	2	5	1.1250	0.0250	0.0222	10.3760	4.9900	2.2162	0.4441	64.6570	3.8650	2.2162	0.5734	34.4834						
C	790827	1	9	2.1500	0.0000	0.0000	7.4663	4.8333	1.1198	0.2317	28.6676	2.6833	1.1198	0.4173	15.6193						
C	790910	7	3	1.4924	0.1678	0.0842	15.5597	3.3833	0.5949	0.1758	27.5443	1.3905	0.5949	0.4278	11.1561						
C	791011	7	6	1.6643	0.2215	0.1331	27.5383	2.5875	1.2386	0.4787	41.3112	0.9518	1.2155	1.2770	16.2708						

MEAN				1.4120	0.2755	0.2194	14.3111	3.2173	0.8449	0.2830	28.7747	1.7734	0.8629	0.6690	15.2780						
STDV				0.5214	0.1976	0.1321	13.5696	1.1189	0.4863	0.1275	27.7226	1.1053	0.4856	0.3949	14.2168						

COV				0.3696	0.7172	0.6019	0.9482	0.3478	0.5755	0.4506	0.9634	0.6232	0.5628	0.5903	0.9633						
NN				14.0000	13.0000	13.0000	14.0000	15.0000	13.0000	13.0000	15.0000	14.0000	12.0000	12.0000	14.0000						

NO3	PACK				PLUM				EASS				
	DATE	BN	PN	MEAN	SIDW	COV	MIN	DPD	MEAN	SIDW	COV	MIN	DPD
F													
W	780427	5	0	0.4000	0.1068	0.2669	5.2212	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780902	4	1	0.3475	0.0750	0.2157	5.4883	0.3000	-9.0000	-9.0000	9.6334	0.0	-9.0000
W	780306	2	3	0.4450	0.1050	0.2360	4.5057	0.5333	0.1184	0.2220	3.6214	0.1067	0.0872
W	780909	2	1	0.4770	0.0950	0.1407	3.4431	0.6200	-9.0000	-9.0000	3.6031	0.0	-9.0000
W	780910	4	3	0.5625	0.1535	0.2729	3.0141	1.0867	0.0838	0.0771	4.3218	0.5242	0.0838
W	780814	7	0	0.4071	0.0845	0.2075	4.4367	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780609	9	1	0.4650	0.2962	0.3070	7.9518	0.6800	-9.0000	-9.0000	5.6193	0.0	-9.0000
W	780671	5	2	0.5867	0.0730	0.1244	1.3169	0.7900	0.1800	0.2278	1.1379	0.2033	0.1800
W	780626	3	3	0.4047	0.1482	0.1837	16.0948	1.5333	0.1239	0.0808	10.1351	0.7267	0.1239
W	780630	6	1	0.4467	0.1363	0.3052	5.1564	0.4900	-9.0000	-9.0000	7.6955	0.0433	-9.0000
W	780724	10	4	0.4450	0.1409	0.3030	4.7733	0.4425	0.1907	0.4310	4.3708	0.0763	0.1321
W	780728	2	1	0.4200	0.1400	0.2903	3.9189	1.2000	-9.0000	-9.0000	2.4918	0.5800	-9.0000
W	780817	5	2	1.2660	0.1622	0.1281	8.5018	1.0200	0.1800	0.1765	10.3947	0.0	0.0
W	780822	7	0	0.4800	0.1838	0.3830	5.2339	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780823	4	3	0.7250	0.1344	0.1854	11.5066	1.0000	0.3662	0.3359	9.6878	0.3733	0.3574
W	780829	8	5	0.5037	0.1251	0.2483	6.8803	0.5200	0.2088	0.4015	5.6410	0.1065	0.1329
MEAN				0.6064	0.1175	0.2374	8.2152	0.7928	0.2815	0.2241	8.0869	0.2108	0.1784
STDV				0.2335	0.0530	0.0712	3.4473	0.3489	0.0804	0.1265	3.0517	0.2438	0.0960
COV				0.3851	0.3857	0.2998	0.5546	0.4401	0.4433	0.5182	0.5048	1.1566	0.6960
MIN				16.0000	16.0000	16.0000	16.0000	13.0000	8.0000	8.0000	13.0000	13.0000	7.0000

NO3	HACK						PLUM			EXSS				
	DATE	BV	PB	MEAN	STDEV	COV	MN DPO	MEAN	STDEV	COV	MN DPO	MEAN	STDEV	COV
C 79082P	3	4	0.1533	0.0018	0.4032	0.7933	0.1650	0.0357	0.2164	0.9644	0.0200	0.0271	1.3540	0.0640
C 79082Q	5	2	0.0780	0.0306	0.3922	0.6179	0.1250	0.0650	0.5200	0.2459	0.0560	0.0560	1.0000	0.0096
C 790831	0	3	0.0000	0.0000	0.0000	0.0000	0.5467	0.0525	0.0960	1.4758	0.0000	0.0000	0.0000	0.0000
C 790915	2	1	0.2400	0.0400	0.1667	0.3076	0.3400	0.0000	0.0000	0.7590	0.1000	0.0000	0.0000	0.2232
C 790623	2	3	0.0750	0.0450	0.6000	0.0368	0.0900	0.0082	0.0907	0.0613	0.0150	0.0082	0.5443	0.0108
C 790701	3	1	0.2400	0.0455	0.1894	0.4044	0.1700	0.0000	0.0000	0.6759	0.00	0.0000	0.0000	0.00
C 790725	3	10	0.1567	0.0655	0.4180	0.1769	0.3250	0.0970	0.2984	5.9718	0.1730	0.0871	0.5037	3.2536
C 790801	2	5	0.1600	0.0700	0.4375	1.2751	0.2500	0.1302	0.5209	1.0274	0.0980	0.1230	1.2554	0.2328
C 790802	3	8	0.2067	0.0602	0.2912	0.6107	0.0950	0.0287	0.3023	0.7661	0.00	0.00	0.0000	0.00
C 790806	4	2	0.1675	0.0286	0.1708	2.2683	0.1200	0.0900	0.7500	1.5260	0.0213	0.0213	1.0000	0.2631
C 790809	8	2	0.1712	0.0276	0.1611	0.7694	0.1450	0.0250	0.1724	0.7620	0.00	0.00	0.0000	0.00
C 790820	2	5	0.0750	0.0050	0.0682	0.6810	0.4180	0.3819	0.9137	1.7914	0.3430	0.3819	1.1134	1.1131
C 790827	1	9	0.2100	0.0000	0.0000	0.7293	0.3789	0.0681	0.1796	2.2042	0.1689	0.0681	0.4030	0.9267
C 790910	6	3	0.1150	0.0685	0.2174	2.6941	0.3300	0.0294	0.0892	2.7039	0.0233	0.0184	0.7890	0.1869
C 791011	7	4	0.0857	0.1822	0.2657	10.6766	0.5000	0.2228	0.3777	8.0288	0.0711	0.1231	1.7320	0.4825
MEAN	0.2096	0.0562	0.2908	2.1458	0.2726	0.0950	0.3483	2.2002	0.0778	0.0762	0.9695	0.4845		
STDEV	0.1674	0.0409	0.1460	2.7186	0.1566	0.0492	0.2511	2.2071	0.0929	0.1016	0.3981	0.4367		
COV	0.7901	0.7273	0.4951	1.2669	0.5744	1.0449	0.7210	1.0031	1.1932	1.3315	0.4106	1.7127		
NN	14.0000	13.0000	13.0000	14.0000	15.0000	13.0000	13.0000	15.0000	14.0000	12.0000	10.0000	14.0000		

NH4	F	DATE	BN	DN	BACK				PLUM				EXSS			
					MEAN	STDV	COV	MM DPO	MEAN	STDV	COV	MM DPO	MEAN	STDV	COV	MM DPO
					-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	W	790827	5	0	0.2472	0.0437	0.1522	3.7636	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
	W	790902	4	1	0.4050	0.0569	0.1404	6.9312	0.3900	-9.0000	-9.0000	12.5624	0.0	-9.0000	-9.0000	0.0
	W	790906	2	3	0.8050	0.0450	0.1180	8.9245	0.9100	0.1219	0.1360	5.8562	0.1247	0.0019	0.1252	1.0158
	W	790909	2	1	1.1900	0.1600	0.1356	5.7360	1.1900	-9.0000	-9.0000	6.9157	0.0100	-9.0000	-9.0000	0.0581
	W	790910	4	3	0.7050	0.2594	0.1679	3.8468	1.5013	0.2081	0.1384	6.0063	0.7983	0.2081	0.2606	3.2499
	W	790914	7	0	0.3524	0.1373	0.5438	3.7861	0.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
	W	790919	8	1	0.4681	0.1849	0.1910	8.5649	0.7100	-9.0000	-9.0000	5.8672	0.0	-9.0000	-9.0000	0.0
	W	790921	5	2	0.4820	0.1786	0.3069	1.3490	1.5750	0.9250	0.5873	2.0439	0.9930	0.9250	0.9315	1.1530
	W	790926	3	4	0.5000	0.0163	0.0327	10.3878	0.6575	0.1424	0.1660	7.0560	0.3515	0.1424	0.3082	2.8746
	W	790930	6	1	0.5817	0.1194	0.2052	7.5507	0.5300	-9.0000	-9.0000	8.3237	0.0	-9.0000	-9.0000	0.0
	W	790924	10	4	0.4130	0.1150	0.2805	4.4425	0.4275	0.1108	0.2591	4.4330	0.0510	0.0736	1.4427	0.3857
	W	790928	2	1	0.7050	0.0250	0.0355	5.1432	0.6400	-9.0000	-9.0000	1.3290	0.0	-9.0000	-9.0000	0.0
	W	790817	5	2	0.4720	0.7655	0.7876	7.3648	0.5400	0.1400	0.2593	5.4554	0.0	0.0	-9.0000	0.0
	W	790822	7	0	0.1843	0.0306	0.1663	2.2052	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
	W	790823	4	3	0.4000	0.1347	0.2245	9.5418	0.8847	0.1428	0.2444	4.3782	0.1231	0.1281	1.0300	0.2150
	W	790829	8	5	0.5675	0.2732	0.4814	8.0938	0.5400	0.2504	0.4638	5.6711	0.1090	0.1359	1.2465	1.0002
	MEAN				0.4604	0.1623	0.2606	6.1020	0.8077	0.2583	0.2815	5.9022	0.1826	0.2131	0.8434	0.8118
	STDV				0.2661	0.1730	0.1942	2.6230	0.3745	0.2557	0.1519	2.6447	0.3149	0.2749	0.3994	1.0695
	COV				0.4419	1.0662	0.7454	0.4299	0.4637	0.9900	0.5397	0.4414	1.5938	1.2900	0.4826	1.3174
	MM				16.0000	16.0000	16.0000	16.0000	13.0000	8.0000	8.0000	13.0000	13.0000	8.0000	7.0000	13.0000

DATE	MN	DN	BACK				PLUM				EXSS			
			MEAN	STDEV	COV	MM DBD	MEAN	STDEV	COV	MM DBD	MEAN	STDEV	COV	MM DBD
F	780878	3	3	0.4733	0.2654	0.5606	3.2288	0.2020	0.0457	0.2264	1.6607	0.0	0.0	-9.0000 0.0
C	780879	5	2	0.1020	0.0350	0.3434	0.8386	0.2740	0.0500	0.1025	0.0671	0.1720	0.0500	0.2907 0.5328
C	780881	0	3	0.0000	0.0000	0.0000	0.0000	0.7333	0.1112	0.1514	1.9662	0.0000	0.0000	0.0000 0.0000
C	780882	2	1	0.4250	0.1250	0.2941	0.5466	0.3600	0.0000	-9.0000	0.0037	0.0	-9.0000	-9.0000 0.0
C	780883	0	2	0.0000	0.0000	0.0000	0.0000	0.1200	0.0700	0.5833	0.1057	-9.0000	-9.0000	-9.0000 -9.0000
C	780884	3	1	0.2257	0.0330	0.1456	0.1863	0.2100	0.0000	0.0000	5.7761	0.0	0.0000	0.0000 0.0
C	780885	3	10	0.1633	0.0645	0.4197	4.5313	0.3270	0.1178	0.3603	6.0423	0.1660	0.1143	0.6884 3.1703
C	780886	2	5	0.1500	0.0500	0.3333	1.2371	0.2400	0.2736	1.1402	0.6317	0.1400	0.2420	1.7285 0.1830
C	780887	3	8	0.1167	0.2811	0.2477	1.0648	0.1787	0.1361	0.7617	1.4672	0.0179	0.0474	2.6458 0.1507
C	780888	4	2	0.3075	0.2058	0.6694	4.0319	0.1350	0.1250	0.9259	1.6849	0.0	0.0	-9.0000 0.0
C	780889	8	2	0.1107	0.0302	0.2542	0.5147	0.1150	0.0450	0.3913	0.6030	0.0206	0.0206	1.0000 0.1079
C	780890	2	4	0.1750	0.0150	0.0857	1.5742	0.3725	0.2103	0.5665	2.1039	0.2087	0.1978	0.9478 0.6594
C	780891	1	9	0.2300	0.0000	0.0000	0.7987	0.5289	0.1254	0.2371	3.0845	0.2989	0.1254	0.4195 1.6007
C	780892	6	3	0.0000	0.0480	0.1332	2.8337	0.6867	0.1367	0.1991	5.5918	0.3267	0.1367	0.4185 2.6313
C	780893	7	4	0.2154	0.0608	0.1895	3.5102	0.3537	0.2191	0.6194	5.7506	0.1462	0.2134	1.4598 2.5904
MEAN			0.2511	0.0998	0.3597	2.2231	0.3225	0.1282	0.4879	2.5486	0.1152	0.1043	1.0665	0.9011
STDEV			0.1126	0.0924	0.2103	1.4650	0.1871	0.0679	0.3002	2.0800	0.1430	0.0832	0.7218	1.1357
COV			0.4444	0.9259	0.6402	0.6590	0.5802	0.5298	0.6152	0.8161	0.9815	0.7975	0.6768	1.2603
NN			13.0000	12.0000	12.0000	13.0000	15.0000	13.0000	13.0000	15.0000	13.0000	11.0000	9.0000	13.0000

CL	DATE	RW	PN	BACK			PLUM			EXSS		
				MEAN	STDV	COV	MEAN	STDV	COV	MEAN	STDV	COV
				MIN	MAX	DEV	MIN	MAX	DEV	MIN	MAX	DEV
W	780827	5	0	0.1220	0.0248	0.2034	1.5771	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780902	4	1	0.0575	0.0130	0.2259	0.9460	0.0500	-9.0000	-9.0000	1.6106	0.0
W	780906	2	3	0.1050	0.0050	0.0676	1.2243	0.1800	0.1042	0.5791	1.4374	0.0867
W	780909	2	1	0.1451	0.0450	0.3103	0.6828	0.1500	-9.0000	-9.0000	0.8717	0.0050
W	780910	4	3	0.1075	0.0512	0.4760	0.5816	0.2300	0.0294	0.1280	0.8897	0.1225
W	780914	7	0	0.1145	0.0461	0.3849	1.9008	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780809	8	1	0.2275	0.0638	0.2804	1.9939	0.2000	-9.0000	-9.0000	1.6527	0.0
W	780821	6	2	0.3600	0.2335	0.6445	0.8900	0.2300	0.0600	0.2609	0.3283	0.0
W	780826	3	3	0.1700	0.0356	0.2094	3.6204	0.2467	0.0403	0.1358	2.7907	0.1267
W	780830	5	1	0.1933	0.1435	0.7422	1.9281	0.1200	-9.0000	-9.0000	1.8846	0.0
W	780774	10	4	0.1546	0.0949	0.5949	1.7230	0.1225	0.0517	0.4217	1.2194	0.0126
W	780724	2	1	0.2150	0.0550	0.2558	1.8079	0.2400	-9.0000	-9.0000	0.6884	0.0250
W	780817	5	2	0.5300	0.5067	0.9561	4.0628	0.2100	0.0200	0.0952	2.1503	0.0
W	780822	7	0	0.2985	0.1605	0.5375	3.6989	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780823	4	3	0.2375	0.2731	0.9119	4.8743	0.2133	0.0618	0.2650	2.1439	0.0075
W	780829	8	5	0.1850	0.0819	0.4961	2.2439	0.1192	0.0660	0.5561	1.0746	0.0100
MEAN				0.2045	0.1146	0.4557	2.0972	0.1832	0.0562	0.3050	1.4292	0.0305
STDV				0.1151	0.1259	0.2563	1.2331	0.0640	0.0243	0.1797	0.6831	0.0460
COV				0.5626	1.0969	0.5625	0.5080	0.3536	0.4482	0.5892	0.4779	1.5093
RW				16.0000	16.0000	16.0000	16.0000	13.0000	8.0000	8.0000	13.0000	6.0000

CL	BACK						PLUM						EXSS					
	DATE	HW	DN	SEAS	STDEV	COV	MN	DPD	STDEV	COV	MN	DPD	STDEV	COV	MN	DPD		
C	790829	3	3	0.1000	0.0455	0.4546	0.6472	0.0567	0.0125	0.2201	0.4631	0.0	0.0	-9.0000	0.0			
C	790829	5	2	0.1500	0.1477	0.9348	0.8198	0.1900	0.1100	0.5789	0.4227	0.0710	0.0710	1.0000	0.1263			
C	790811	0	3	0.0000	0.0000	0.0000	0.0000	0.1900	0.1061	0.5587	0.5058	0.0000	0.0000	0.0000	0.0000			
C	790815	0	0	0.0000	0.0000	0.0000	0.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000			
C	790821	2	3	0.1400	0.0300	0.1667	0.1038	0.1667	0.0492	0.2953	0.1225	0.0167	0.0236	1.4142	0.0157			
C	790821	3	1	0.1300	0.0141	0.1044	2.4035	0.0600	-9.0000	-9.0000	1.6503	0.0	-9.0000	-9.0000	0.0			
C	790725	3	10	0.2367	0.2781	1.1752	10.2305	0.1030	0.0759	0.7369	2.0646	0.0053	0.0160	3.0000	0.1213			
C	790801	2	5	0.0700	0.0400	0.5714	0.5329	0.1020	0.0700	0.6860	0.5528	0.0380	0.0662	1.7408	0.2267			
C	790802	3	8	0.2267	0.2007	0.8455	0.5327	0.1587	0.1482	0.9335	1.0817	0.0379	0.1003	2.6458	0.1704			
C	790804	4	2	0.0625	0.0083	0.1327	0.9182	0.0750	0.0250	0.3333	0.9957	0.0188	0.0188	1.0000	0.2321			
C	790808	8	3	0.0900	0.0532	0.5906	0.3867	0.2133	0.1929	0.9044	0.5050	0.1433	0.1752	1.2222	0.2531			
C	790820	2	5	0.2100	0.1200	0.5714	2.3393	0.2740	0.1941	0.7083	1.1804	0.1060	0.1627	1.5347	0.1995			
C	790827	1	9	0.1600	0.0000	0.0000	1.2502	0.1733	0.0690	0.3979	0.9872	0.0	0.0	-9.0000	0.0			
C	790910	6	3	0.0917	0.0561	0.6120	0.7247	0.0733	0.0170	0.2318	0.5953	0.0	0.0	-9.0000	0.0			
C	791011	7	4	0.0800	0.0830	0.9430	1.2949	0.0725	0.0334	0.6613	1.0023	0.0032	0.0048	1.4866	0.0493			

MEAN																		
STDEV																		
COV																		
MN																		

CA	HACA				PLUM				EXSS								
	DATE	HW	PH	SLW	CON	SN	DPO	MEAN	STDV	CON	SN	DPO	MEAN	STDV	CON	SN	DPO
W	790827	5	0	0.4040	0.3560	0.8811	4.0844	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	0.0000
W	790922	4	1	0.3000	0.0696	0.1620	8.1155	0.5800	-9.0000	-9.0000	19.6825	0.1500	-9.0000	-9.0000	4.8317		
W	790826	2	3	0.5500	0.1700	0.3031	5.2610	0.6767	0.2457	0.3631	4.9064	0.1800	0.1883	1.0643	1.7167		
W	790929	2	1	0.4400	0.0500	0.0735	3.3621	0.8000	-9.0000	-9.0000	4.6492	0.1200	-9.0000	-9.0000	0.6974		
W	790910	4	2	0.5625	0.0517	0.0952	2.8369	1.2600	0.1000	0.0794	5.3749	0.7175	0.1000	0.1394	3.1065		
W	790814	7	0	0.1624	0.1121	0.5825	2.7945	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	
W	790829	4	1	0.2400	0.1313	0.4529	2.1163	0.1300	-9.0000	-9.0000	1.0743	0.0	-9.0000	-9.0000	0.0		
W	790821	5	2	0.6400	0.2733	0.4271	1.4668	0.8100	0.0900	0.1111	1.2043	0.1700	0.0900	0.5294	0.2245		
W	790826	3	2	0.0331	0.2917	0.2768	20.4352	1.7150	0.0350	0.0204	13.1990	0.6617	0.0350	0.4529	4.9911		
W	790830	6	1	0.1250	0.0310	0.2477	1.6751	0.0400	-9.0000	-9.0000	0.6282	0.0	-9.0000	-9.0000	0.0		
W	790724	10	3	0.2590	0.1163	0.4506	2.2451	0.2067	0.0655	0.3169	2.6182	0.0107	0.0151	1.4142	0.1570		
W	790729	2	0	0.5851	0.3950	0.6752	2.8368	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	
W	790817	5	2	0.4629	0.0652	0.1844	3.0295	0.3600	0.1000	0.2778	3.6298	0.0	0.0	-9.0000	0.0		
W	790822	7	0	0.4524	0.2211	0.4982	4.7364	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	
W	790823	4	3	0.3525	0.2041	0.5912	5.2524	0.2167	0.0681	0.4065	1.8764	0.0	0.0	-9.0000	0.0		
W	790829	8	5	0.2317	0.0612	0.3475	3.6294	0.2140	0.1131	0.5283	2.5150	0.0465	0.0573	1.2323	0.4783		

	MEAN			0.4532	0.1653	0.3964	4.6168	0.5841	0.1067	0.2629	5.0298	0.1714	0.0607	0.7167	1.3503		
	STDV			0.2212	0.1104	0.2154	4.3493	0.4438	0.0580	0.1657	5.2210	0.2416	0.0600	0.5272	1.8204		
	CON			0.4840	0.4680	0.5516	0.9511	0.8233	0.5534	0.6304	1.0380	1.4102	0.9885	0.7166	1.3482		
	SN			18.0000	18.0000	18.0000	15.0000	12.0000	8.0000	8.0000	12.0000	12.0000	8.0000	6.0000	12.0000		

MO	HALF				PLUM				EISS			
	DATE	MO	DA	PR	MEAN	STDV	COV	MN DEF	MEAN	STDV	COV	MN DEF
W	790827	5	0	0.0160	0.0080	0.5000	0.2279	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790927	4	1	0.0550	0.0050	0.0000	1.0337	0.0000	-9.0000	-9.0000	-9.0000	1.1274
W	790828	2	3	0.0450	0.0350	0.4118	0.7388	0.1133	0.0330	0.2042	0.7833	0.0333
W	790829	2	1	0.1100	0.0100	0.0000	0.5563	0.1100	-9.0000	-9.0000	-9.0000	0.0
W	790919	4	2	0.0750	0.0335	0.4472	0.4479	0.1650	0.0050	0.0303	0.6866	0.0900
W	790818	7	0	0.0100	0.0200	0.6667	0.6601	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790829	4	1	0.0575	0.0192	0.1458	0.4287	0.0400	-9.0000	-9.0000	-9.0000	0.0
W	790821	5	2	0.1000	0.0377	0.1360	0.2623	0.1700	0.0500	0.2041	0.2404	0.0640
W	790826	3	0	0.2300	0.0636	0.2773	0.4694	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790830	5	1	0.0220	0.0075	0.1402	0.2123	0.0100	-9.0000	-9.0000	-9.0000	0.0
W	790724	10	4	0.0400	0.0196	0.4760	0.3970	0.0600	0.0644	1.0737	0.6172	0.0310
W	790728	2	1	0.0650	0.0360	0.7778	0.4004	0.0100	-9.0000	-9.0000	-9.0000	0.0
W	790817	4	2	0.0700	0.0141	0.2020	0.4202	0.0550	0.0750	0.4545	0.5442	0.0050
W	790822	7	0	0.0720	0.0249	0.3419	0.7972	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790823	4	2	0.0200	0.0112	0.6472	0.3560	0.0200	0.0	0.0	0.2456	0.0
W	790829	6	5	0.0747	0.0215	0.7468	0.3407	0.0260	0.0162	0.6249	0.2601	0.0065
<hr/>												
	MEAN				0.0663	0.0224	0.4055	0.7086	0.0724	0.0277	0.3055	0.6205
	STDV				0.0505	0.0148	0.1943	0.9057	0.0545	0.0217	0.3437	0.7239
	COV				0.7564	0.4462	0.4792	1.4036	0.7526	0.7042	0.8690	1.1667
	MN				16.0000	16.0000	16.0000	16.0000	12.0000	7.0000	12.0000	12.0000
									0.0221	0.0213	0.9473	0.1875
									0.0285	0.0209	0.5166	0.3111
									1.2893	0.9815	0.5454	1.0596
									12.0000	7.0000	6.0000	12.0000

MO

E	DATE	MO	PLUM			EASS		
			REF AM	STDM	LOW	REF AM	STDM	LOW
C	1900000	1	0.0167	0.0100	0.1339	0.0	0.0	-9.0000
C	1900000	2	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	3	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	4	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	5	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	6	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	7	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	8	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	9	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	10	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	11	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	12	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	13	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	14	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	15	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	16	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	17	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	18	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	19	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	20	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	21	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	22	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	23	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	24	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	25	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	26	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	27	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	28	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	29	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	30	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000
C	1900000	31	0.0167	0.0100	0.1339	0.0250	0.0250	1.0000

NA	HACK					PLUM					FESS				
	DATE	RN	PN	STAY	SIDV	COV	MN DEP	STUV	COV	MN DEP	STDV	MEAN	STDV	COV	MN DEP
W	790927	5	0	0.0500	0.0126	0.2510	0.7168	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790927	4	1	0.0650	0.0150	0.2304	1.1810	0.1100	-9.0000	-9.0000	3.5432	0.0450	-9.0000	-9.0000	1.4495
M	790928	2	3	0.0300	0.0400	0.4664	0.7583	0.1100	0.0174	0.3402	0.7923	0.0247	0.0109	1.1582	0.2641
W	790929	2	1	0.0400	0.0200	0.7722	0.4307	0.1200	-9.0000	-9.0000	0.6974	0.0300	-9.0000	-9.0000	0.1743
W	790910	4	2	0.1150	0.0541	0.4703	0.6754	0.1500	0.0100	0.0687	0.6166	0.0350	0.0100	0.2857	0.1357
M	790916	1	0	0.1021	0.0414	0.4579	1.6411	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790920	7	1	0.0871	0.0444	0.5158	0.7371	0.0500	-9.0000	-9.0000	0.4954	0.0	-9.0000	-9.0000	0.0
W	790921	6	2	0.1313	0.1064	0.6543	0.4057	0.0950	0.0350	0.1684	0.1715	0.0	0.0	-9.0000	0.0
M	790926	3	3	0.0233	0.0044	0.6041	0.6693	0.0733	0.0125	0.1701	0.7206	0.0500	0.0125	0.2694	0.6961
W	790930	6	1	0.0943	0.0745	0.4632	0.7985	0.2600	-9.0000	-9.0000	4.0833	0.1717	-9.0000	-9.0000	2.6961
W	790924	10	4	0.0410	0.0442	0.5404	0.7540	0.0675	0.0653	0.9679	0.5811	0.0243	0.0420	1.7320	0.1569
M	790928	2	0	0.0300	0.0400	0.4800	0.5245	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790917	5	2	0.0600	0.0136	0.2949	0.1104	0.0300	0.0200	0.6667	0.2900	0.0020	0.0020	1.0000	0.0186
W	790922	7	0	0.0714	0.0116	0.6335	0.2740	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	790923	4	3	0.0400	0.0421	1.1244	1.1518	0.0200	0.0141	0.7071	0.2634	0.0	0.0	-9.0000	0.0
W	790929	8	5	0.0112	0.0033	0.2940	0.1524	0.0200	0.0063	0.3162	0.2336	0.0090	0.0059	0.6597	0.1024
STUV				0.0124	0.0425	0.5514	0.6804	0.0910	0.0251	0.4504	1.0175	0.0124	0.0129	0.8677	0.4578
COV				0.0174	0.0124	0.2443	0.1720	0.0640	0.0186	0.2416	1.2624	0.0453	0.0145	0.5182	0.7775
W				0.0225	0.7611	0.5229	0.5419	0.6406	0.7397	0.6295	1.2172	1.3803	1.1220	0.6114	1.6984
W				14.0000	16.0000	14.0000	16.0000	12.0000	14.0000	14.0000	12.0000	12.0000	14.0000	14.0000	12.0000

NA	DATE	BY	EN	MILE			PUM			ERSS					
				MEAN	STDEV	LOW	MEAN	STDEV	LOW	MEAN	STDEV	LOW			
C	790828	3	3	0.1000	0.0510	0.5099	0.6775	0.0100	0.0000	0.0000	0.2493	0.0	0.0	-9.0000	0.0
C	790829	5	1	0.0720	0.0212	0.3216	0.5617	0.0000	-9.0000	-9.0000	0.3118	0.0080	-9.0000	-9.0000	0.0312
C	790831	0	3	-9.0000	-4.0000	-9.0000	-9.0000	0.1500	0.0052	0.5000	0.3071	-9.0000	-9.0000	-9.0000	-9.0000
C	790835	2	1	0.1200	0.0600	0.3113	0.1545	0.4200	-9.0000	-9.0000	0.9176	0.3000	-9.0000	-9.0000	0.6697
C	790839	1	1	0.0100	-9.0000	-9.0000	0.0242	0.0500	-9.0000	-9.0000	0.0071	0.0200	-9.0000	-9.0000	0.0189
C	790841	1	1	0.0111	0.0000	0.0000	1.1151	0.0200	-9.0000	-9.0000	0.5501	0.0	-9.0000	-9.0000	0.0
C	790845	3	10	0.1111	0.2099	1.2946	1.6108	0.0520	0.0337	0.6482	1.0189	0.0	0.0	-9.0000	0.0
C	790846	2	4	0.0100	0.0	0.0	0.0914	0.0375	0.0476	1.2702	0.2184	0.0275	0.0676	1.7320	0.1740
C	790848	2	8	0.0200	0.0000	0.0000	0.1011	0.0502	0.0020	1.1029	0.3658	0.0315	0.0577	1.5181	0.2147
C	790849	4	2	0.0275	0.0125	0.5378	0.3144	0.0000	0.0000	0.0000	0.5490	0.0125	0.0000	0.0000	0.1716
C	790849	8	3	0.0037	0.0293	0.6659	0.1914	0.0267	0.0125	0.4677	0.1014	0.0	0.0	-9.0000	0.0
C	790850	2	4	0.0000	0.0100	0.2500	0.3193	0.0175	0.0173	0.4277	0.2753	0.0500	0.0012	1.2287	0.1075
C	790851	1	9	0.1200	-9.0000	-9.0000	0.4167	0.0778	0.0781	1.0000	0.4690	0.0178	0.0503	2.8284	0.1178
C	790910	0	3	0.0511	0.0189	0.6670	0.4444	0.0011	0.0000	0.1000	0.3545	0.0	0.0	-9.0000	0.0
C	791011	1	4	0.0218	0.0131	0.3125	0.3007	0.0025	0.0189	0.6218	0.1127	0.0200	0.0122	1.3278	0.6095
MEAN				0.0676	0.0366	0.5539	0.8855	0.0802	0.0392	0.6792	0.5185	0.0355	0.0249	1.4421	0.1368
STDEV				0.0002	0.0000	0.0000	1.0198	0.0359	0.0100	0.6777	0.2728	0.0748	0.0259	0.8120	0.1885
LOW				0.0000	1.4671	0.7200	2.0776	1.1988	0.7921	0.6765	0.6222	2.1070	1.0400	0.5789	1.3634
				14.0000	12.0000	12.0000	14.0000	15.0000	11.0000	11.0000	15.0000	14.0000	10.0000	6.0000	14.0000

K	MACH				PLUM				EASS				
	DATE	HM	PH	SEAL	STDV	CON	MM DPN	CON	MM DPN	STDV	CON	MM DPN	CON
F	780827	5	0	0.0300	0.0063	0.2108	0.4174	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	780828	4	1	0.0600	0.0141	0.2357	1.0635	0.0800	-9.0000	-9.0000	2.5769	0.0200	-9.0000
M	780829	2	3	0.0650	0.0050	0.0769	0.7824	0.1100	0.0510	0.4435	0.8381	0.0467	0.0494
M	780830	2	1	0.1100	0.0100	0.0909	0.5390	0.0400	-9.0000	-9.0000	0.4649	0.0	-9.0000
M	780831	4	2	0.0675	0.0148	0.2191	0.3381	0.1200	0.0200	0.1667	0.5230	0.0525	0.0200
M	780832	7	0	0.0414	0.0210	0.5068	0.6302	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	780833	7	1	0.1143	0.0645	0.5820	0.8398	0.0700	-9.0000	-9.0000	0.5785	0.0	-9.0000
M	780834	4	1	0.1525	0.2417	0.6597	0.7791	0.3400	-9.0000	-9.0000	0.3955	0.0	-9.0000
M	780835	3	3	0.0567	0.0184	0.3328	1.1481	0.1331	0.0205	0.1561	1.3007	0.0767	0.0205
M	780836	5	1	0.1350	0.1412	1.0456	1.9442	0.0300	-9.0000	-9.0000	0.4712	0.0	-9.0000
M	780837	10	4	0.0920	0.0685	0.9357	0.7076	0.1300	0.1120	0.8617	1.5046	0.0765	0.0858
M	780838	2	1	0.0850	0.0050	0.0588	0.6507	0.0300	-9.0000	-9.0000	0.0623	0.0	-9.0000
M	780817	5	2	0.3260	0.5763	1.7570	2.8549	0.0200	0.0100	0.5000	0.1969	0.0	0.0
M	780822	7	0	0.0314	0.0196	0.6232	0.3314	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	780823	4	3	0.0400	0.0682	0.7577	1.4694	0.0300	0.0000	0.0009	0.3124	0.0	0.0
M	780829	8	5	0.0575	0.1076	1.8706	0.8279	0.0300	0.0167	0.5578	0.2670	0.0005	0.0010
MEAN				0.1066	0.0865	0.6181	0.9552	0.0926	0.0324	0.3864	0.7294	0.0210	0.0253
STDV				0.0924	0.1409	0.5344	0.6373	0.0818	0.0354	0.2739	0.6673	0.0295	0.0297
CON				0.4702	1.4285	0.9647	0.6672	0.8843	1.0760	0.7088	0.9149	1.4072	1.1752
				16.0000	16.0000	16.0000	16.0000	13.0000	7.0000	7.0000	13.0000	13.0000	5.0000

K	BACK						PLUM						EXSS								
	F	DATE	4 th	PN	MEAN	STDV	COV	MIN	DPO	MEAN	STDV	COV	MIN	DPO	MEAN	STDV	COV	MIN	DPO		
C	780824	3	3	0.1134	0.0474	0.4595	0.8738			0.0233	0.0047	0.2020	0.1935		0.0	0.0	-9.0000	0.0			
C	780829	5	2	0.0540	0.0366	0.6302	0.4866			0.2100	0.1500	0.7143	0.5953		0.1520	0.1500	0.9868	0.4052			
C	780811	0	3	-9.0000	-9.0000	-9.0000	-9.0000			0.0800	0.0245	0.3062	0.2099		-9.0000	-9.0000	-9.0000	-9.0000			
C	780914	2	1	0.0450	0.0050	0.0508	0.1086			0.1200	-9.0000	-9.0000	0.2679		0.0350	-9.0000	-9.0000	0.0781			
C	780823	1	1	0.1700	-9.0000	-9.0000	0.1373			0.0900	-9.0000	-9.0000	0.0946		0.0	-9.0000	-9.0000	0.0			
C	780801	3	1	0.0467	0.0236	0.5051	0.2967			0.0100	-9.0000	-9.0000	0.2751		0.0	-9.0000	-9.0000	0.0			
C	780825	3	10	0.0947	0.1156	1.1955	4.2229			0.0200	0.0155	0.7746	0.3847		0.0	0.0	-9.0000	0.0			
C	780801	2	4	0.0100	0.0	0.0	0.0914			0.0900	0.1386	1.5396	0.5707		0.0800	0.1386	1.7321	0.5063			
C	780802	2	8	0.0150	0.0050	0.3333	0.0579			0.0462	0.0667	1.4421	0.2825		0.0331	0.0657	1.9838	0.1709			
C	780806	4	2	0.0350	0.0180	0.5151	0.4205			0.2100	0.1500	0.7143	3.0836		0.1750	0.1500	0.8571	2.6032			
C	780809	8	3	0.0625	0.0455	0.7277	0.2788			0.0400	0.0424	1.0607	0.1966		0.0125	0.0177	1.4142	0.0654			
C	780820	2	2	0.0200	0.0	0.0	0.1854			0.0100	0.0	0.0	0.1886		0.0	0.0	-9.0000	0.0			
C	780827	1	9	0.2400	-9.0000	-9.0000	0.8335			0.0889	0.0661	0.7433	0.6233		0.0022	0.0063	2.8284	0.0217			
C	780910	4	3	0.1000	0.1045	1.0647	0.8179			0.0200	0.0082	0.4082	0.1606		0.0	0.0	-9.0000	0.0			
C	781011	7	4	0.0171	0.0433	1.1666	0.4822			0.0625	0.0363	0.5810	0.9924		0.0296	0.0318	1.0719	0.5052			
				MFB1																	
				0.0778	0.0615	0.5497	0.6946			0.0747	0.0586	0.7072	0.5407		0.0371	0.0509	1.5535	0.3111			
				STDV																	
				0.0621	0.0409	0.6177	1.0192			0.0625	0.0547	0.4458	0.7184		0.0562	0.0613	0.6436	0.6621			
				COV																	
				0.7977	0.9459	0.7084	1.4569			0.8358	0.9335	0.6304	1.3288		1.5145	1.2046	0.4143	2.1279			
				MIN																	
				14.0000	12.0000	12.0000	14.0000			15.0000	12.0000	12.0000	15.0000		14.0000	11.0000	7.0000	14.0000			

F	HACS				PLUM				EXSS						
	DATE	BU	DN	MEAN	STDV	COV	MM DPO	MEAN	STDV	COV	MM DPO	MEAN	STDV	COV	MM DPO
W	790827	0	0	-4.0000	-9.0000	-4.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790827	6	1	0.0300	0.0346	1.1547	1.0712	0.0100	-9.0000	-9.0000	0.3221	0.0	-9.0000	-9.0000	0.0
W	790826	2	3	0.0250	0.0050	0.2000	0.2605	0.0667	0.0170	0.3642	0.3403	0.0217	0.0170	0.7845	0.1879
W	790829	2	1	0.0450	0.0150	0.3333	0.2110	0.0100	-9.0000	-9.0000	0.0581	0.0	-9.0000	-9.0000	0.0
W	790829	4	3	0.775	0.0192	0.6983	0.1629	0.0433	0.0199	0.4351	0.1589	0.0159	0.0189	1.1909	0.0514
W	790826	7	0	0.0224	0.0070	0.3062	0.3514	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790829	8	1	0.0000	0.0000	0.0007	0.3770	0.0400	-9.0000	-9.0000	0.3305	0.0000	-9.0000	-9.0000	0.0000
W	790829	6	2	0.0483	0.0121	0.2510	0.1099	0.0450	0.0050	0.1111	0.0669	0.0008	0.0008	1.0000	0.0009
W	790826	3	3	0.0000	0.0000	0.0009	0.8378	0.0400	0.0000	0.0009	0.3850	0.0000	0.0	0.0	0.0000
W	790829	6	1	0.0343	0.0037	0.0972	0.5707	0.0400	-9.0000	-9.0000	0.6282	0.0017	-9.0000	-9.0000	0.0262
W	790724	10	4	0.0400	0.0000	0.0008	0.4300	0.0400	0.0000	0.0009	0.4378	0.0000	0.0	0.0	0.0000
W	790728	2	1	0.0350	0.0050	0.1429	0.2792	0.0500	-9.0000	-9.0000	0.1034	0.0150	-9.0000	-9.0000	0.0311
W	790817	5	2	0.0612	0.0564	0.9209	0.4571	0.1015	0.0075	0.0739	1.0455	0.0403	0.0075	0.1861	0.4103
W	790829	7	0	0.0700	0.0764	1.0915	0.9531	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790829	4	3	0.0442	0.0422	0.8738	0.7962	0.0300	0.0188	0.6278	0.3958	0.0	0.0	-9.0000	0.0
W	790829	8	5	0.0227	0.0047	0.2059	0.3172	0.0424	0.0390	0.9202	0.7933	0.0211	0.0381	1.8035	0.5339
MEAN				0.0395	0.0188	0.4185	0.4790	0.0615	0.0131	0.3164	0.3897	0.0090	0.0103	0.7083	0.0955
STDV				0.0132	0.0225	0.3940	0.2904	0.0212	0.0122	0.3118	0.2790	0.0123	0.0128	0.6324	0.1697
COV				0.3330	1.1949	0.9510	0.6062	0.5113	0.9184	0.9444	0.7159	1.3767	1.2430	0.8916	1.7767
DP				15.0000	15.0000	15.0000	15.0000	13.0000	8.0000	8.0000	13.0000	13.0000	7.0000	13.0000	13.0000

F				RACK				PLUM				EXSS			
F	DATE	BN	PN	MEAN	STDEV	COV	MM.DPO	MEAN	STDEV	COV	MM.DPO	MEAN	STDEV	COV	MM.DPO
C	790828	2	0	0.0200	0.0100	0.5000	0.1524	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
C	790829	3	1	0.0200	0.0082	0.4082	0.1318	0.0200	-9.0000	-9.0000	0.0780	0.0	-9.0000	-9.0000	0.0
C	790831	0	3	-9.0000	-9.0000	-9.0000	-9.0000	0.0267	0.0094	0.3536	0.0732	-9.0000	-9.0000	-9.0000	-9.0000
C	790815	0	0	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
C	790823	2	3	0.0400	0.0000	0.0007	0.0244	0.0400	0.0000	0.0009	0.0269	0.0000	0.0	0.0	0.0000
C	790801	3	1	0.0400	0.0000	0.0003	0.07350	0.0400	-9.0000	-9.0000	1.1002	0.0000	-9.0000	-9.0000	0.0000
C	790725	3	10	0.0400	0.0000	0.0009	0.7693	0.0390	0.0030	0.0769	0.6914	0.0000	0.0000	0.3333	0.0000
C	790801	2	5	0.0400	0.0000	0.0007	0.3654	0.0388	0.0024	0.0619	0.2105	0.0000	0.0000	0.5000	0.0000
C	790802	3	8	0.0243	0.0165	0.5823	0.0800	0.0400	0.0000	0.0007	0.3561	0.0117	0.0000	0.0011	0.1039
C	790806	4	2	0.0227	0.0173	0.7584	0.3687	0.0400	0.0000	0.0007	0.5490	0.0173	0.0	0.0	0.2367
C	790809	8	2	0.0320	0.0139	0.4355	0.1602	0.0140	0.0080	0.5714	0.0737	0.0	0.0	-9.0000	0.0
C	790820	2	4	0.0575	0.0525	0.9130	0.3650	0.0570	0.0087	0.1536	0.5351	0.0038	0.0063	1.1689	0.0149
C	790827	1	8	0.0100	-9.0000	-9.0000	0.0347	0.0227	0.0086	0.3780	0.1375	0.0134	0.0074	0.5519	0.0786
C	790910	4	3	0.0125	0.0041	0.3258	0.1124	0.0153	0.0019	0.1230	0.1261	0.0028	0.0019	0.6655	0.0233
C	791011	7	4	0.0114	0.0035	0.3062	0.1886	0.0125	0.0043	0.3664	0.1708	0.0021	0.0037	1.7320	0.0145
				MEAN				STDEV				COV			
				0.0288				0.0105				0.3527			
				0.0137				0.0141				0.2974			
				0.4764				1.3440				0.8431			
				13.0000				12.0000				12.0000			
				0.0312				0.0042				0.1879			
				0.0130				0.0036				0.1845			
				0.4173				0.8563				0.9820			
				13.0000				11.0000				11.0000			
				0.0043				0.0017				0.5481			
				0.0059				0.0025				0.5502			
				1.3954				1.4212				1.0039			
				12.0000				10.0000				9.0000			

FE	HACK							PLUM			EASS		
	DATE	BN	PI	MEAN	STDV	COV	MIN	DPD	MEAN	STDV	COV	MIN	DPD
W	790827	5	0	0.0202	0.0143	0.7101	0.2511		-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790902	4	1	0.0322	0.0131	0.4063	0.5041		0.0870	-9.0000	-9.0000	2.8024	0.0548
W	790905	2	1	0.0455	0.0055	0.0836	0.4973		0.1167	0.0082	0.0705	0.7355	0.0302
W	790909	2	1	0.0529	0.0445	0.7120	0.2725		0.1190	-9.0000	-9.0000	0.6916	0.0565
W	790910	4	3	0.0712	0.0430	0.5030	0.4261		0.1960	0.0711	0.3629	0.7485	0.1248
W	790914	7	0	0.0201	0.0214	1.0619	0.2927		-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790609	8	1	0.0145	0.0075	0.3872	0.1776		0.0460	-9.0000	-9.0000	0.3801	0.0265
W	790621	6	2	0.0247	0.0082	0.3075	0.0627		0.0855	0.0485	0.5673	0.1116	0.0588
W	790624	2	1	0.0221	0.0	0.0	0.4069		0.0450	-9.0000	-9.0000	0.1387	0.0230
W	790630	3	1	0.0210	0.0016	0.0778	0.2510		0.0140	-9.0000	-9.0000	0.2199	0.0
W	790724	10	4	0.0429	0.0377	0.8801	0.4022		0.0500	0.0355	0.7106	0.5793	0.0174
W	790728	2	1	0.0250	0.0020	0.2308	0.2161		0.0460	-9.0000	-9.0000	0.0314	0.0180
W	790817	6	2	0.0563	0.0652	0.6769	0.6512		0.1500	0.0620	0.4133	1.4907	0.0578
W	790822	8	2	0.0535	0.0344	0.4529	0.6067		0.0735	0.0065	0.1156	0.1884	0.0200
W	790823	6	5	0.0151	0.0055	0.3585	0.2305		0.0668	0.0419	0.6465	0.8593	0.0495
W	790829	6	5	0.0106	0.0077	0.7441	0.1230		0.0392	0.0137	0.3492	0.3968	0.0292

MEAN				0.0391	0.0198	0.4935	0.3673		0.0808	0.0162	0.4045	0.6739	0.0605
STDV				0.0260	0.0187	0.3016	0.2281		0.0479	0.0227	0.2176	0.6968	0.0294
COV				0.4450	0.9456	0.6111	0.6211		0.5935	0.6277	0.5379	1.0340	0.7271
MIN				12.0000	16.0000	16.0000	16.0000		14.0000	8.0000	8.0000	14.0000	8.0000

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PLUM										EXSS									
F	DATE	RUN	DN	MEAN	STDEV	COV	MM DPO	MEAN	STDEV	COV	MM DPO	MEAN	STDEV	COV	MM DPO				
C	790628	2	2	0.0135	0.0015	0.1111	0.0869	0.0260	0.0150	0.5769	0.2324	0.0138	0.0137	1.0000	0.1257				
C	790829	5	2	0.0522	0.0571	1.0932	0.2527	0.0530	0.0270	0.5094	0.1905	0.0139	0.0139	1.0000	0.0542				
C	790911	0	2	0.0000	0.0000	0.0000	0.0000	0.0325	0.0145	0.3867	0.1066	0.0000	0.0000	0.0000	0.0000				
C	790915	1	1	0.0370	0.0000	0.0000	0.0445	0.0570	0.0000	0.0000	0.1273	0.0200	0.0000	0.0000	0.0446				
C	790923	1	1	0.0100	0.0000	0.0000	0.0081	0.0550	0.0000	0.0000	0.0239	0.0450	0.0000	0.0000	0.0195				
C	790926	1	1	0.0130	0.0000	0.0000	0.1915	0.0050	0.0000	0.0000	0.1375	0.0	0.0000	0.0000	0.0				
C	790928	3	10	0.0027	0.0017	0.6374	0.0249	0.0220	0.0188	0.6535	0.4436	0.0193	0.0188	0.9713	0.3962				
C	790801	2	4	0.0325	0.0275	0.8462	0.2236	0.0410	0.0280	0.6440	0.2868	0.0172	0.0199	1.1510	0.1261				
C	790802	3	4	0.0143	0.0118	0.8428	0.0678	0.0529	0.0544	1.2184	0.4560	0.0360	0.0636	1.7653	0.3012				
C	790804	4	2	0.0115	0.0027	0.2341	0.1478	0.0305	0.0155	0.5082	0.4394	0.0190	0.0155	0.6158	0.2816				
C	790809	5	2	0.0374	0.0270	0.7123	0.1668	0.0205	0.0155	0.7561	0.1073	0.0	0.0	0.0000	0.0				
C	790820	2	5	0.0100	0.0010	0.3000	0.1024	0.1566	0.0961	0.6138	0.6619	0.1466	0.0961	0.6556	0.5675				
C	790827	1	9	0.0240	0.0000	0.0000	0.0903	0.0038	0.0647	0.7728	0.5113	0.0581	0.0644	1.1089	0.3549				
C	790910	6	3	0.0257	0.0121	0.4722	0.2293	0.0057	0.0159	0.2425	0.5342	0.0400	0.0159	0.3981	0.3231				
C	791011	7	4	0.0024	0.0110	0.4924	0.3243	0.0425	0.0227	0.5346	0.6788	0.0201	0.0227	1.1320	0.3138				
<hr/>																			
MEAN																			
STDEV																			
COV																			
NN																			

CU	BACK				PLUM				EARS						
	HN	PN	MEAN	STDEV	COV	HN DEP	MEAN	STDEV	COV	HN DEP	MEAN	STDEV	COV	HN DEP	
F	DATE	HN	PN	MEAN	STDEV	COV	HN DEP	MEAN	STDEV	COV	HN DEP	MEAN	STDEV	COV <td>HN DEP</td>	HN DEP
M	7/10/87	5	0	0.0010	0.0000	0.0013	0.0136	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
M	7/10/87	4	1	0.0027	0.0019	0.0043	0.0816	0.0090	-0.0000	-0.0000	0.2997	0.0063	-0.0000	-0.0000	0.2013
M	7/10/86	2	3	0.0055	0.0025	0.0045	0.0866	0.0360	0.0000	0.2234	0.1930	0.0305	0.0080	0.2637	0.1595
M	7/10/89	2	1	0.0029	0.0010	0.5000	0.0091	0.0100	-0.0000	-0.0000	0.0581	0.0080	-0.0000	-0.0000	0.0465
M	7/10/90	4	3	0.0062	0.0070	1.1164	0.0359	0.0140	0.0016	0.1166	0.0562	0.0078	0.0016	0.2107	0.0317
M	7/10/91	7	0	0.0026	0.0031	1.2095	0.0375	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
M	7/10/86	4	2	0.0022	0.0007	0.2940	0.0199	0.0130	0.0040	0.3077	0.1138	0.0107	0.0040	0.3721	0.0936
M	7/10/87	4	3	0.0034	0.0023	0.5914	0.0094	0.0673	0.0649	0.9636	0.0865	0.0635	0.0649	1.0218	0.0804
M	7/10/87	2	1	0.0010	0.0	0.0	0.0185	0.0020	-0.0000	-0.0000	0.0062	0.0010	-0.0000	-0.0000	0.0031
M	7/10/80	3	1	0.0020	0.0008	0.4082	0.0227	0.0070	-0.0000	-0.0000	0.1099	0.0050	-0.0000	-0.0000	0.0785
M	7/10/79	10	4	0.0031	0.0016	0.5291	0.0337	0.0225	0.0131	0.5833	0.2700	0.0194	0.0131	0.6765	0.2361
M	7/10/79	2	1	0.0025	0.0045	0.5294	0.0804	0.0170	-0.0000	-0.0000	0.0353	0.0085	-0.0000	-0.0000	0.0177
M	7/10/81	4	2	0.0029	0.0007	0.7425	0.0219	0.0440	0.0170	0.3964	0.4748	0.0412	0.0170	0.4130	0.4454
M	7/10/82	4	3	0.0022	0.0015	0.6573	0.0246	0.0853	0.0649	0.7604	0.5369	0.0831	0.0649	0.7810	0.5272
M	7/10/82	7	5	0.0023	0.0020	0.8660	0.0355	0.0442	0.0432	0.9763	0.6355	0.0422	0.0428	1.0165	0.6128
M	7/10/89	8	5	0.0022	0.0019	0.8535	0.0322	0.0218	0.0096	0.4394	0.3092	0.0195	0.0096	0.4900	0.2826
MEAN				0.0031	0.0020	0.5595	0.0352	0.0281	0.0251	0.5286	0.2264	0.0248	0.0251	0.5826	0.2012
STDEV				0.0014	0.0017	0.3333	0.0245	0.0236	0.0241	0.2956	0.1941	0.0237	0.0241	0.2885	0.1912
COV				0.4145	0.0706	0.5958	0.6968	0.8421	0.9566	0.5592	0.8559	0.9589	0.9589	0.4953	0.9504
HN				15.0000	15.0000	16.0000	16.0000	16.0000	9.0000	9.0000	16.0000	16.0000	9.0000	9.0000	16.0000

CU	DATE	RN	PN	HACK			PLUM			EXSS						
				MEAN	STDEV	COV	MM DEP	MEAN	STDEV	COV	MM DEP	MEAN	STDEV	COV	MM DEP	
F																
C	790828	2	2	0.0010	0.0	0.0061	0.0150	0.0100	0.6667	0.1347	0.0140	0.0100	0.7143	0.1261		
C	790829	5	2	0.0078	0.0078	1.0043	0.0420	0.0250	0.5952	0.1532	0.0342	0.0250	0.7310	0.1276		
C	790831	0	2	-0.0000	-0.0000	-0.0000	0.0145	0.0025	0.1724	0.0399	-0.0000	-0.0000	-0.0000	-0.0000		
C	790915	1	1	0.0110	-0.0000	-0.0000	0.0220	-0.0000	-0.0000	0.0491	0.0110	-0.0000	-0.0000	0.0246		
C	790823	2	1	0.0015	0.0005	0.3333	0.0030	-0.0000	-0.0000	0.0013	0.0015	-0.0000	-0.0000	0.0006		
C	790701	1	1	0.0010	-0.0000	-0.0000	0.0020	-0.0000	-0.0000	0.0550	0.0010	-0.0000	-0.0000	0.0275		
C	790725	3	10	0.0020	0.0004	0.4083	0.0187	0.0252	1.3499	0.4003	0.0167	0.0252	1.5116	0.3647		
C	790801	2	5	0.0045	0.0015	0.3333	0.0176	0.0117	0.6442	0.1046	0.0131	0.0117	0.8923	0.0758		
C	790802	4	8	0.0060	0.0037	0.5124	0.0532	0.0878	1.6495	0.4391	0.0474	0.0878	1.8526	0.3878		
C	790804	6	2	0.0047	0.0048	1.0326	0.0055	0.0005	0.0909	0.0762	0.0008	0.0005	0.6000	0.0121		
C	790809	9	2	0.0037	0.0015	0.4066	0.0090	0.0080	0.4889	0.0471	0.0067	0.0067	1.0000	0.0349		
C	790820	2	6	0.0060	0.0030	0.7500	0.0758	0.0486	0.6407	0.3071	0.0718	0.0486	0.6764	0.2733		
C	790827	1	9	0.0030	-0.0000	-0.0000	0.0773	0.1075	1.3896	0.4782	0.0746	0.1073	1.4393	0.4611		
C	790910	7	3	0.0016	0.0005	0.3149	0.0397	0.0073	0.1845	0.3291	0.0381	0.0073	0.1921	0.3162		
C	791011	7	4	0.0043	0.0035	0.8246	0.0252	0.0224	0.9089	0.4338	0.0210	0.0229	1.0947	0.3679		

MEAN				0.0040	0.0025	0.5473	0.0274	0.0280	0.0298	0.7668	0.2032	0.0251	0.0321	0.9731	0.1847	
STDEV				0.0027	0.0022	0.3091	0.0194	0.0237	0.0331	0.4793	0.1674	0.0239	0.0335	0.4538	0.1612	
COV				0.6799	0.8943	0.5647	0.7062	0.8463	1.1124	0.6251	0.8234	0.9511	1.0450	0.4664	0.8679	
NN				1.0000	11.0000	11.0000	14.0000	15.0000	12.0000	12.0000	15.0000	14.0000	11.0000	11.0000	14.0000	

N1	DATE	HU	DI	MACK			PLUM			EXSS		
				MEAN	STDV	COV	MEAN	STDV	COV	MEAN	STDV	COV
W	780827	5	0	0.0010	0.0000	0.0013	0.0136	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	780902	4	1	0.0012	0.0004	0.3664	0.0302	0.0030	-9.0000	-9.0000	-9.0000	0.0564
W	780906	2	1	0.0015	0.0005	0.3331	0.0221	0.0170	0.0059	0.3663	0.0874	0.0155
W	780909	2	1	0.0010	0.0	0.0	0.0050	0.0040	-9.0000	-9.0000	0.0232	0.0030
W	780910	4	3	0.0015	0.0005	0.3333	0.0080	0.0047	0.0012	0.2473	0.0186	0.0032
W	780916	7	0	0.0014	0.0010	0.7348	0.0219	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
W	790609	8	2	0.0010	0.0000	0.0017	0.0094	0.0065	0.0005	0.0769	0.0579	0.0055
W	790621	4	3	0.0014	0.0007	0.3748	0.0044	0.0530	0.0503	0.9492	0.0676	0.0512
W	790626	2	1	0.0010	0.0	0.0	0.0145	0.0010	-9.0000	-9.0000	0.0031	0.0
W	790610	3	1	0.0017	0.0009	0.5657	0.0264	0.0010	-9.0000	-9.0000	0.0157	0.0
W	790724	10	4	0.0020	0.0024	1.1832	0.0174	0.0127	0.0064	0.5034	0.1598	0.0107
W	790729	2	1	0.0020	0.0010	0.5000	0.0187	0.0070	-9.0000	-9.0000	0.0145	0.0050
W	790817	6	2	0.0012	0.0004	0.3194	0.0083	0.0365	0.0205	0.5616	0.3570	0.0353
W	790822	6	3	0.0011	0.0003	0.2940	0.0124	0.0257	0.0144	0.5799	0.1451	0.0245
W	790823	7	5	0.0010	0.0000	0.0017	0.0144	0.0182	0.0169	0.0280	0.2493	0.0182
W	790829	8	5	0.0014	0.0007	0.5062	0.0204	0.0066	0.0042	0.6400	0.1078	0.0053
				MEAN	0.0014	0.0006	0.3435	0.0158	0.0141	0.0134	0.1017	0.0128
				STDV	0.0003	0.0006	0.3112	0.0074	0.0147	0.0146	0.2627	0.0999
				COV	0.2546	1.0604	0.9060	0.4651	1.0368	1.0908	0.4923	0.9820
				SN	16.0000	16.0000	16.0000	16.0000	16.0000	9.0000	16.0000	9.0000

NI	DATE	HW	PN	HACK			PLUM			EXSS							
				SEAU	STDV	COV	HN	DPD	COV	HN	DPD	COV	HN	DPD			
F																	
C	780828	2	2	0.0010	0.0	0.0	0.0061			0.0045	0.0025	0.5556	0.0402	0.0035	0.0025	0.7143	0.0315
C	780829	5	2	0.0024	0.0023	0.9718	0.0170			0.0260	0.0230	0.8846	0.0995	0.0236	0.0230	0.9746	0.0916
C	780811	0	2	-0.0000	-0.0000	-0.0000	-0.0000			0.0045	0.0025	0.5556	0.0128	-0.0000	-0.0000	-0.0000	-0.0000
C	780815	1	1	0.0020	-0.0000	-0.0000	0.0026			0.0200	-0.0000	-0.0000	0.0444	0.0190	-0.0000	-0.0000	0.0402
C	780823	2	1	0.0010	0.0	0.0	0.0009			0.0020	-0.0000	-0.0000	0.0009	0.0010	-0.0000	-0.0000	0.0004
C	780801	1	1	0.0010	-0.0000	-0.0000	0.0147			0.0010	-0.0000	-0.0000	0.0275	0.0	-0.0000	-0.0000	0.0
C	780725	3	10	0.0017	0.0009	0.5657	0.0513			0.0063	0.0098	1.5521	0.1384	0.0050	0.0096	1.9002	0.1153
C	780801	2	5	0.0010	0.0	0.0	0.0091			0.0050	0.0034	0.6812	0.0303	0.0040	0.0034	0.8515	0.0239
C	780802	4	8	0.0027	0.0020	0.7441	0.0073			0.0135	0.0200	1.4787	0.1100	0.0110	0.0198	1.8082	0.0893
C	780804	4	2	0.0020	0.0012	0.5774	0.0243			0.0035	0.0025	0.7143	0.0514	0.0020	0.0020	1.0000	0.0301
C	780809	9	2	0.0017	0.0009	0.5657	0.0075			0.0105	0.0095	0.9048	0.0549	0.0092	0.0092	1.0000	0.0479
C	780820	2	4	0.0020	0.0010	0.5000	0.0218			0.0335	0.0215	0.6606	0.1102	0.0317	0.0212	0.6698	0.0987
C	780827	1	9	0.0010	-0.0000	-0.0000	0.0035			0.0448	0.0659	1.4726	0.2791	0.0438	0.0659	1.5062	0.2730
C	780910	7	3	0.0016	0.0010	0.6880	0.0112			0.0320	0.0261	0.8153	0.2724	0.0304	0.0261	0.8574	0.2595
C	781011	7	4	0.0020	0.0014	0.7071	0.0341			0.0190	0.0221	1.1609	0.3370	0.0170	0.0221	1.2875	0.3063
MEAN				0.0016	0.0010	0.4818	0.0151			0.0151	0.0174	0.9513	0.1073	0.0143	0.0186	1.1476	0.1006
STDV				0.0006	0.0007	0.3183	0.0135			0.0132	0.0171	0.3558	0.1024	0.0131	0.0172	0.4062	0.1000
COV				0.3397	0.7510	0.6606	0.8928			0.8728	0.9806	0.3739	0.9549	0.9191	0.9266	0.3552	0.9941
HN				14.0000	11.0000	11.0000	14.0000			15.0000	12.0000	12.0000	15.0000	14.0000	11.0000	11.0000	14.0000

PB	HACK							PLUM				EASS			
	DATE	NO	PR	YEAR	STDV	COV	MM DDO	MEAN	STDV	COV	MM DDO	MEAN	STDV	COV	MM DDO
C	790829	2	2	0.0050	0.0010	0.2000	0.0335	0.0070	0.0020	0.2857	0.0616	0.0020	0.0020	1.0000	0.0193
C	790829	5	2	0.0032	0.0012	0.3044	0.0219	0.0075	0.0045	0.6000	0.0274	0.0044	0.0044	1.0000	0.0172
C	790831	6	2	0.0000	0.0000	0.0000	0.0000	0.0145	0.0015	0.1034	0.0406	0.0000	0.0000	0.0000	0.0000
C	790915	1	1	0.0040	0.0000	0.0000	0.0105	0.0110	0.0000	0.0000	0.0246	0.0030	0.0000	0.0000	0.0067
C	790929	1	1	0.0010	0.0000	0.0000	0.0008	0.0040	0.0000	0.0000	0.0017	0.0030	0.0000	0.0000	0.0013
C	790930	1	1	0.0000	0.0000	0.0000	0.1178	0.0100	0.0000	0.0000	0.2751	0.0020	0.0000	0.0000	0.0550
C	790725	3	10	0.0040	0.0014	0.3536	0.1058	0.0087	0.0037	0.4209	0.1697	0.0047	0.0037	0.7791	0.0945
C	790801	2	4	0.0035	0.0005	0.1429	0.0306	0.0050	0.0012	0.2449	0.0327	0.0015	0.0012	0.8165	0.0101
C	790802	3	8	0.0040	0.0004	0.2041	0.0124	0.0112	0.0113	1.0044	0.1181	0.0012	0.0113	1.5586	0.0825
C	790804	4	2	0.0030	0.0010	0.3333	0.0367	0.0030	0.0000	0.0007	0.0412	0.0000	0.0	0.0	0.0000
C	790809	8	2	0.0025	0.0019	0.3318	0.0250	0.0045	0.0005	0.1111	0.0236	0.0	0.0	0.0000	0.0
C	790820	2	6	0.0040	0.0	0.0	0.0372	0.0188	0.0054	0.2450	0.1266	0.0148	0.0054	0.3618	0.0328
C	790827	1	9	0.0040	0.0000	0.0000	0.0208	0.0268	0.0226	0.8424	0.1611	0.0208	0.0226	1.0857	0.1246
C	790910	6	3	0.0073	0.0011	0.1504	0.0566	0.0127	0.0038	0.2977	0.1041	0.0053	0.0038	0.7071	0.0438
C	791011	7	6	0.0147	0.0031	0.2109	0.2363	0.0195	0.0094	0.4414	0.3046	0.0061	0.0084	1.3594	0.1027

MEAN		0.0055 0.0012 0.2292 0.0534 0.0109 0.0055 0.3894 0.1008 0.0054 0.0057 0.8668 0.0647													
STDV		0.0032 0.0004 0.1109 0.0603 0.0064 0.0061 0.2885 0.0900 0.0056 0.0063 0.4257 0.0434													
COV		0.5794 0.4620 0.4841 1.1284 0.5888 1.1158 0.7400 0.9929 1.0462 1.0992 0.4954 0.9306													
NN		14.0000 10.0000 10.0000 16.0000 15.0000 12.0000 12.0000 15.0000 14.0000 11.0000 10.0000 14.0000													

ZN	DATE	HN	PN	BACK		PLUM		EXSS							
				MEAN	STDV	COV	MM DPO	MEAN	STDV	COV	MM DPO				
F															
C	780828	2	2	0.0040	0.0	0.0	0.0244	0.0150	0.0000	0.0004	0.1299	0.0110	0.0	0.0	0.0952
C	780829	5	2	0.0064	0.0024	0.3776	0.0458	0.0215	0.0165	0.7674	0.0602	0.0150	0.0150	1.0000	0.0420
C	780831	0	2	-9.0000	-9.0000	-9.0000	-9.0000	0.0190	0.0070	0.3684	0.0517	-9.0000	-9.0000	-9.0000	-9.0000
C	780835	1	1	0.0150	-9.0000	-9.0000	0.0197	0.0080	-9.0000	-9.0000	0.0179	0.0	-9.0000	-9.0000	0.0
C	780837	1	1	0.0040	-9.0000	-9.0000	0.0048	0.0060	-9.0000	-9.0000	0.0026	0.0	-9.0000	-9.0000	0.0
C	780841	1	1	0.0240	-9.0000	-9.0000	0.3535	0.0040	-9.0000	-9.0000	0.1100	0.0	-9.0000	-9.0000	0.0
C	780845	3	10	0.0040	0.0016	0.2041	0.1839	0.0157	0.0146	0.9287	0.3112	0.0084	0.0141	1.6821	0.1822
C	780847	2	4	0.0040	0.0050	0.6250	0.0598	0.0217	0.0161	0.7409	0.1419	0.0140	0.0159	1.1350	0.0916
C	780852	3	8	0.0240	0.0291	1.0022	0.0658	0.0415	0.0266	0.6400	0.3142	0.0166	0.0227	1.3640	0.1076
C	780854	4	2	0.0062	0.0045	0.7277	0.0784	0.0295	0.0275	0.9322	0.4418	0.0254	0.0254	1.0000	0.3823
C	780859	8	2	0.0237	0.0291	1.2264	0.1017	0.0205	0.0185	0.9024	0.1073	0.0076	0.0076	1.0000	0.0399
C	780820	2	6	0.0040	0.0010	0.1250	0.0776	0.0127	0.0061	0.6417	0.0789	0.0057	0.0046	0.8065	0.0168
C	780827	1	9	0.0150	-9.0000	-9.0000	0.0521	0.0048	0.0025	0.5200	0.0303	0.0	0.0	-9.0000	0.0
C	780910	6	3	0.0103	0.0133	1.2871	0.0723	0.0057	0.0017	0.2999	0.0468	0.0	0.0	-9.0000	0.0
C	781011	7	4	0.0104	0.0160	1.4740	0.1270	0.0020	0.0000	0.0014	0.0308	0.0	0.0	-9.0000	0.0

MEAN				0.0125	0.0102	0.7049	0.0905	0.0152	0.0114	0.5466	0.1250	0.0075	0.0096	0.9985	0.0684
STDV				0.0076	0.0107	0.4989	0.0852	0.0105	0.0035	0.3175	0.1248	0.0079	0.0091	0.4546	0.1023
COV				0.6071	1.0454	0.7077	0.9422	0.6942	0.8301	0.5787	0.9985	1.0549	0.9465	0.4553	1.4957
NN				14.0000	10.0000	10.0000	14.0000	15.0000	12.0000	12.0000	15.0000	14.0000	11.0000	8.0000	14.0000

[illegible]

AL	DATE	BU	PH	WACK			PLUM			EXSS			COV			MN			DO		
				MEAN	STDEV	COV	MEAN	STDEV	COV	MEAN	STDEV	COV	MEAN	STDEV	COV	MEAN	STDEV	COV	MEAN	STDEV	COV
F																					
C	790828	2	2	0.0070	0.0010	0.1429	0.0457	0.0105	0.0085	0.8095	0.0950	0.0060	0.0060	1.0000	0.0549						
C	790829	5	2	0.0146	0.0138	0.9335	0.1039	0.0155	0.0055	0.3548	0.0542	0.0022	0.0022	1.0000	0.0086						
C	790831	0	2	0.0000	0.0000	0.0000	0.0000	0.0160	0.0070	0.4375	0.0456	0.0000	0.0000	0.0000	0.0000						
C	790835	1	1	0.0330	0.0000	0.0000	0.0433	0.0200	0.0000	0.0000	0.0446	0.0	0.0	0.0000	0.0000	0.0					
C	790837	1	1	0.0040	0.0000	0.0000	0.0044	0.0350	0.0000	0.0000	0.0151	0.0290	0.0000	0.0000	0.0125						
C	790841	1	1	0.0030	0.0000	0.0000	0.0042	0.0010	0.0000	0.0000	0.0275	0.0	0.0	0.0000	0.0000	0.0					
C	790845	3	10	0.0067	0.0017	0.2550	0.1025	0.0082	0.0046	0.5610	0.1556	0.0024	0.0040	1.6519	0.0524						
C	790849	2	4	0.0130	0.0320	0.9697	0.2162	0.0157	0.0131	0.8295	0.1106	0.0	0.0	0.0000	0.0						
C	790852	3	8	0.0120	0.0089	0.8250	0.0291	0.0162	0.0078	0.5474	0.1412	0.0065	0.0057	1.2669	0.0497						
C	790856	4	2	0.0042	0.0034	0.8044	0.0519	0.0110	0.0020	0.1818	0.1537	0.0068	0.0020	0.2963	0.0953						
C	790859	8	2	0.0126	0.0127	1.0073	0.0534	0.0050	0.0	0.0	0.0263	0.0	0.0	0.0000	0.0						
C	790860	2	6	0.0050	0.0	0.0	0.0665	0.0380	0.0363	0.9555	0.1848	0.0330	0.0363	1.1003	0.1426						
C	790867	1	9	0.0270	0.0000	0.0000	0.0764	0.0364	0.0260	0.7140	0.2165	0.0168	0.0242	1.4395	0.0932						
C	790910	6	3	0.0215	0.0223	1.0368	0.2009	0.0087	0.0024	0.2720	0.0712	0.0	0.0	0.0000	0.0						
C	791011	7	4	0.0081	0.0049	0.5308	0.1344	0.0112	0.0065	0.5774	0.1436	0.0042	0.0065	1.0858	0.0624						
				MEAN	0.0137	0.0102	0.6405	0.0826	0.0164	0.0100	0.5201	0.0990	0.0075	0.0077	1.1051	0.0394					
				STDEV	0.0094	0.0099	0.3629	0.0611	0.0110	0.0102	0.2728	0.0618	0.0105	0.0111	0.3731	0.0436					
				COV	0.7145	0.9716	0.5665	0.7390	0.6697	1.0270	0.5245	0.6240	1.4080	1.4404	0.3376	1.1069					
				NN	14.0000	10.0000	10.0000	14.0000	15.0000	12.0000	12.0000	15.0000	14.0000	11.0000	8.0000	14.0000					

CR	HACK				PLUM				EXSS						
	DATE	RM	DN	MEAN	STDEV	COV	MM.DEG	MEAN	STDEV	COV	MM.DEG	MEAN	STDEV	COV	MM.DEG
F															
M	790827	5	0	0.0005	0.0001	0.1739	0.0062	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	790902	4	0	0.0005	0.0000	0.0008	0.0095	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	790904	2	3	0.0007	0.0002	0.3333	0.0111	0.0005	0.0	0.0	0.0030	0.0	0.0	-9.0000	0.0
M	790909	2	1	0.0005	0.0	0.0	0.0025	0.0005	-9.0000	-9.0000	0.0029	0.0	-9.0000	-9.0000	0.0
M	790910	4	2	0.0005	0.0000	0.0008	0.0026	0.0005	0.0	0.0	0.0021	0.0	0.0	-9.0000	0.0
M	790914	2	0	0.0005	0.0000	0.0014	0.0081	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
M	790909	4	1	0.0005	0.0000	0.0014	0.0047	0.0005	-9.0000	-9.0000	0.0041	0.0	-9.0000	-9.0000	0.0
M	790921	6	2	0.0005	0.0000	0.0013	0.0011	0.0015	0.0010	0.6667	0.0019	0.0010	0.0010	1.0000	0.0011
M	790924	2	1	0.0005	0.0	0.0	0.0032	0.0005	-9.0000	-9.0000	0.0015	0.0	-9.0000	-9.0000	0.0
M	790930	3	1	0.0005	0.0	0.0	0.0057	0.0005	-9.0000	-9.0000	0.0079	0.0	-9.0000	-9.0000	0.0
M	790724	10	4	0.0006	0.0002	0.3333	0.0066	0.0007	0.0002	0.3333	0.0074	0.0002	0.0002	1.0000	0.0016
M	790724	2	1	0.0005	0.0	0.0	0.0037	0.0005	-9.0000	-9.0000	0.0010	0.0	-9.0000	-9.0000	0.0
M	790917	6	2	0.0014	0.0016	1.1421	0.0102	0.0007	0.0002	0.3333	0.0075	0.0	0.0	-9.0000	0.0
M	790922	8	2	0.0005	0.0000	0.0014	0.0056	0.0005	0.0	0.0	0.0012	0.0	0.0	-9.0000	0.0
M	790823	6	5	0.0005	0.0000	0.0013	0.0074	0.0005	0.0000	0.0012	0.0054	0.0	0.0	-9.0000	0.0
M	790829	8	5	0.0005	0.0000	0.0014	0.0073	0.0005	0.0000	0.0012	0.0059	0.0	0.0	-9.0000	0.0

	MEAN			0.0006	0.0001	0.1245	0.0064	0.0006	0.0002	0.1470	0.0060	0.0001	0.0002	1.0000	0.0002
	STDEV			0.0002	0.0004	0.2800	0.0028	0.0003	0.0003	0.2355	0.0024	0.0003	0.0003	0.0	0.0005
	COV			0.3027	2.9005	2.2965	0.4461	0.4397	1.7303	1.9105	0.6092	2.8964	2.1858	0.0	2.3816
	MM			16.0000	16.0000	16.0000	16.0000	13.0000	8.0000	8.0000	13.0000	13.0000	8.0000	2.0000	13.0000

CR	BACK				PLUM				EXSS								
	DATE	HW	DN	MEAN	STDEV	COV	MM DPN	MEAN	STDEV	COV	MM DPN	MEAN	STDEV	COV	MM DPN		
F																	
C	790829	2	2	0.0005	0.0	0.0	0.0030	0.0005	0.0	0.0	0.0043	0.0	0.0	-9.0000	0.0		
C	790829	5	2	0.0012	0.0014	1.1667	0.0106	0.0005	0.0	0.0	0.0016	0.0	0.0	-9.0000	0.0		
C	790831	0	2	0.0000	0.0000	0.0000	0.0000	0.0005	0.0	0.0	0.0014	0.0000	0.0000	-8.0000	-8.0000		
C	790915	1	1	0.0005	-9.0000	-9.0000	0.0007	0.0005	-9.0000	-9.0000	0.0011	0.0	-9.0000	-9.0000	0.0		
C	790823	1	1	0.0005	-9.0000	-9.0000	0.0004	0.0005	-9.0000	-9.0000	0.0002	0.0	-9.0000	-9.0000	0.0		
C	790731	1	1	0.0010	-9.0000	-9.0000	0.0147	0.0005	-9.0000	-9.0000	0.0134	0.0	-9.0000	-9.0000	0.0		
C	790725	3	10	0.0005	0.0	0.0	0.0096	0.0005	0.0000	0.0005	0.0059	0.0	0.0	-9.0000	0.0		
C	790801	2	4	0.0007	0.0002	0.3333	0.0062	0.0009	0.0004	0.4738	0.0059	0.0003	0.0003	1.2247	0.0018		
C	790802	3	4	0.0012	0.0009	0.8081	0.0028	0.0017	0.0018	1.0102	0.0159	0.0009	0.0015	1.6389	0.0082		
C	790805	4	1	0.0007	0.0002	0.3333	0.0116	0.0005	-9.0000	-9.0000	0.0062	0.0	-9.0000	-9.0000	0.0		
C	790809	8	2	0.0021	0.0026	1.2505	0.0093	0.0025	0.0020	0.4000	0.0131	0.0012	0.0012	1.0000	0.0064		
C	790820	2	4	0.0005	0.0	0.0	0.0046	0.0007	0.0004	0.5092	0.0050	0.0002	0.0004	1.5275	0.0008		
C	790827	1	9	0.0005	-9.0000	-9.0000	0.0017	0.0006	0.0003	0.5143	0.0037	0.0001	0.0003	2.8244	0.0006		
C	790910	6	3	0.0006	0.0002	0.3194	0.0044	0.0005	0.0	0.0	0.0041	0.0	0.0	-9.0000	0.0		
C	790831	7	4	0.0008	0.0007	0.8007	0.0129	0.0007	0.0004	0.5773	0.0124	0.0002	0.0003	1.7320	0.0034		

				MEAN				STDEV				COV					
				0.0008				0.0006				0.0005				0.0002	
				0.0000				0.0004				0.0004				0.0004	
				1.5257				1.2453				0.8965				1.7570	
				14.0000				10.0000				10.0000				14.0000	

CD	PACK					PLUM					EXSS								
	F	DATE	HIL	PN	MEAN	STDV	COV	MM	DPD	MEAN	STDV	COV	MM	DPD	MEAN	STDV	COV	MM	DPD
	W	780827	5	0	0.0001	0.0000	0.0013	0.0014	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
	W	780828	4	1	0.0001	0.0000	0.0012	0.0019	0.0001	-9.0000	-9.0000	-9.0000	0.0032	0.0000	-9.0000	-9.0000	-9.0000	0.0000	0.0000
	W	780829	2	3	0.0002	0.0001	0.5000	0.0032	0.0005	0.0001	-9.0000	0.2673	0.0024	0.0003	0.0001	0.6477	0.0016	0.0000	0.0000
	W	780830	2	1	0.0001	0.0	0.0	0.0005	0.0001	-9.0000	-9.0000	-9.0000	0.0006	0.0	-9.0000	-9.0000	0.0	0.0000	0.0
	W	780831	4	3	0.0001	0.0000	0.3464	0.0006	0.0005	0.0004	0.8268	0.0022	0.0003	0.0004	1.0801	0.0017	0.0000	0.0000	0.0017
	W	780832	7	0	0.0001	0.0000	0.3062	0.0018	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	0.0000
	W	780833	4	1	0.0004	0.0000	0.1155	0.0034	0.0005	-9.0000	-9.0000	-9.0000	0.0041	0.0001	-9.0000	-9.0000	0.0010	0.0000	0.0010
	W	780834	5	2	0.0003	0.0003	0.8389	0.0008	0.0004	0.0001	0.3333	0.0006	0.0002	0.0001	1.0000	0.0002	0.0000	0.0000	0.0002
	W	780835	2	1	0.0001	0.0	0.0	0.0018	0.0002	-9.0000	-9.0000	-9.0000	0.0006	0.0001	-9.0000	-9.0000	0.0003	0.0000	0.0003
	W	780836	3	1	0.0003	0.0000	0.1768	0.0032	0.0003	-9.0000	-9.0000	-9.0000	0.0047	0.0000	-9.0000	-9.0000	0.0005	0.0000	0.0005
	W	780837	10	4	0.0002	0.0002	0.7965	0.0021	0.0003	0.0001	0.4724	0.0029	0.0002	0.0001	1.5283	0.0008	0.0000	0.0000	0.0008
	W	780838	2	1	0.0002	0.0002	0.6000	0.0024	0.0004	-9.0000	-9.0000	-9.0000	0.0008	0.0002	-9.0000	-9.0000	0.0003	0.0000	0.0003
	W	780839	4	2	0.0001	0.0001	0.3333	0.0012	0.0008	0.0002	0.2500	0.0085	0.0006	0.0002	0.3077	0.0070	0.0000	0.0000	0.0070
	W	780840	9	2	0.0001	0.0000	0.3464	0.0013	0.0004	0.0002	0.5000	0.0011	0.0003	0.0002	0.7273	0.0008	0.0000	0.0000	0.0008
	W	780841	6	5	0.0001	0.0000	0.3536	0.0020	0.0007	0.0007	1.0262	0.0095	0.0006	0.0007	1.2634	0.0081	0.0000	0.0000	0.0081
	W	780842	8	5	0.0001	0.0000	0.0010	0.0015	0.0003	0.0001	0.3644	0.0039	0.0002	0.0001	0.5301	0.0027	0.0000	0.0000	0.0027
					MEAN	0.0002	0.0001	0.2968	0.0018	0.0004	0.0003	0.5051	0.0033	0.0002	0.0001	0.8606	0.0018	0.0000	0.0018
					STDV	0.0001	0.0001	0.2704	0.0009	0.0002	0.0002	0.2615	0.0027	0.0002	0.0002	0.3948	0.0025	0.0000	0.0025
					COV	0.4447	1.1352	0.9180	0.6813	0.4936	0.7657	0.5178	0.8300	0.9009	0.7616	0.4588	1.3760	0.0000	0.0000
					MS	15.0000	16.0000	16.0000	16.0000	16.0000	8.0000	8.0000	16.0000	16.0000	8.0000	16.0000	16.0000	16.0000	16.0000

CD	HACK				PLUM				EXSS						
	DATE	RU	PN	MEAN	STDV	COV	MM DPN	MEAN	STDV	COV	MM DPN	MEAN	STDV	COV	MM DPN
F															
C	790828	2	2	0.0001 0.0	0.0	0.0006	0.0009	0.0001 0.0	0.0	0.0009	0.0	0.0	0.0	-9.0000	0.0
C	790829	5	2	0.0001 0.0000	0.0013	0.0008	0.0019	0.0005 0.0001	0.2727	0.0019	0.0004	0.0001	0.3333	0.0016	
C	790911	0	2	-9.0000 -9.0000	-9.0000	-9.0000	0.0001	0.0001 0.0	0.0	0.0001	-9.0000	-9.0000	-9.0000	-9.0000	
C	790915	1	1	0.0001 -9.0000	-9.0000	0.0001	0.0002	0.0001 -9.0000	-9.0000	0.0002	0.0	-9.0000	-9.0000	0.0	
C	790923	1	1	0.0001 -9.0000	-9.0000	0.0001	0.0000	0.0001 -9.0000	-9.0000	0.0000	0.0	-9.0000	-9.0000	0.0	
C	790921	1	1	0.0001 -9.0000	-9.0000	0.0015	0.0024	0.0001 -9.0000	-9.0000	0.0024	0.0	-9.0000	-9.0000	0.0	
C	790925	3	10	0.0001 0.0000	0.0004	0.0019	0.0063	0.0003 0.0003	0.4125	0.0063	0.0002	0.0003	1.1818	0.0045	
C	790901	2	4	0.0002 0.0001	0.5000	0.0016	0.0020	0.0003 0.0001	0.4082	0.0020	0.0001	0.0001	1.2247	0.0007	
C	790902	3	7	0.0003 0.0001	0.7874	0.0008	0.0039	0.0005 0.0003	0.5919	0.0039	0.0002	0.0003	1.1586	0.0015	
C	790806	4	2	0.0002 0.0001	0.4738	0.0022	0.0035	0.0002 0.0001	0.2000	0.0035	0.0001	0.0000	0.6667	0.0011	
C	790809	5	2	0.0001 0.0000	0.2940	0.0005	0.0008	0.0001 0.0001	0.3333	0.0008	0.0000	0.0000	1.0000	0.0002	
C	790820	2	6	0.0001 0.0	0.0	0.0009	0.0067	0.0004 0.0002	0.2828	0.0067	0.0007	0.0002	0.3214	0.0059	
C	790827	1	9	0.0001 -9.0000	-9.0000	0.0003	0.0041	0.0007 0.0010	1.4704	0.0041	0.0006	0.0010	1.7351	0.0035	
C	790919	6	3	0.0001 0.0001	0.5092	0.0013	0.0090	0.0011 0.0011	1.0285	0.0090	0.0010	0.0011	1.1909	0.0078	
C	791011	7	4	0.0001 0.0001	0.5093	0.0021	0.0028	0.0002 0.0001	0.3536	0.0028	0.0001	0.0001	0.8118	0.0008	
MEAN				9.0001	0.0001	0.3076	0.0011	0.0004	0.0003	0.4795	0.0030	0.0002	0.0003	0.9646	0.0020
STDV				0.0001	0.0001	0.2745	0.0007	0.0001	0.0004	0.4152	0.0026	0.0003	0.0004	0.4143	0.0024
COV				0.4615	1.2149	0.9924	0.6497	0.8356	1.2691	0.8659	0.8540	1.2170	1.2289	0.4295	1.2190
MM				10.0000	10.0000	10.0000	14.0000	15.0000	12.0000	12.0000	15.0000	14.0000	11.0000	10.0000	14.0000

**ACIDIC PRECIPITATION IN
SOUTH-CENTRAL ONTARIO:
ANALYSIS OF SOURCE REGIONS USING
AIR PARCEL TRAJECTORIES**

May, 1980



Ontario

**Ministry
of the
Environment**

The Honourable
Harry C. Parrott, D.D.S.,
Minister

Graham W. S. Scott, Q.C.,
Deputy Minister

ACIDIC PRECIPITATION IN SOUTH-CENTRAL ONTARIO:

ANALYSIS OF SOURCE REGIONS USING AIR PARCEL TRAJECTORIES

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May, 1980

Abstract

Measurements of precipitation pH, SO_4^{-2} and NO_3^- were taken from August 1976 to April 1979 in the Muskoka-Haliburton region of Ontario. Sea level geostrophic trajectories were used to follow the air mass associated with the event back 48 hours to its 'octant of origin'. Two types of data analysis were carried out, one using the entire data set (composite analysis) and one using only precipitation samples consisting of a single event (event analysis). Concentrations of H^+ , SO_4^{-2} and NO_3^- in event samples from the S, SW, W and NW octants were high. Results from the entire data set showed that precipitation events most commonly occurred with trajectories from the S and SW octants. Both event and composite analyses demonstrated that the majority of H^+ , SO_4^{-2} and NO_3^- deposited at Muskoka-Haliburton was associated with trajectories from the S and SW octants.

INTRODUCTION

The acidification of freshwaters by precipitation has occurred in Scandinavia (Oden 1976), the northeastern U.S.A. (Likens 1976, Schofield 1976) and the greater Sudbury area (Conroy et al. 1975, Beamish 1976). Recent evidence of acidic precipitation in south-central Ontario has been given by Dillon et al. (1978), who reported mean pH values of 3.95-4.38 at 8 sites in Muskoka-Haliburton. The dominant ions in precipitation at this site are H^+ and SO_4^{-2} and the deposition of H^+ and SO_4^{-2} is higher in Muskoka-Haliburton than at any other location on the Canadian Shield measured to date (Scheider et al. 1979a). Effects of acidic precipitation on the poorly buffered freshwaters of the area are discussed by Jeffries et al. (1979) and Scheider et al. (1979b).

In this paper, we attempt to relate the deposition and concentrations of H^+ , SO_4^{-2} and NO_3^{-1} in precipitation collected at Muskoka-Haliburton to pollution source regions through the use of air parcel trajectories. The rationale behind the study is to investigate the relative contributions from the various source regions in order to enable an assessment of proposed strategies aimed at controlling and reducing the acidity in Ontario's precipitation.

Trajectory analysis, to determine the sources of acidity in precipitation, has been applied in Sweden (Munn and Rodhe 1971), Norway (Forland 1973) and at sites in the northeastern U.S.A. (Dittenhoefer and Dethier 1976, Miller et al. (1978). Several authors have studied airborne SO_4^{-2} in Ontario and its relationship to long range transport (Lafleur and Whelpdale 1977, Chung 1978). Summers and Whelpdale (1976) related precipitation pH and SO_4^{-2} to air mass origin in a study performed in August 1976 in eastern Canada. To date, no longer term study has been carried out for this area. Here, we discuss the deposition and concentration of H^+ , SO_4^{-2} and NO_3^{-1} in precipitation collected at 5 sites in Muskoka-Haliburton over the period August 1976 - April 1979 with respect to air parcel trajectories.

DESCRIPTION OF STUDY AREA

Precipitation collectors were located in the Muskoka-Haliburton area of central Ontario (Figure 1). This area is underlain primarily by Precambrian bedrock with a thin, glacially derived overburden. A mixed deciduous/coniferous forest covers the area and no large urban or industrial centres exist within 200 kilometres.

METHODS

Precipitation was collected from August 1976 to April 1979 (33 months) at five sites using automatic, moisture-activated samplers. The samplers opened only during a precipitation event and thus excluded any dry deposition. The periods of collector operation are summarized in Figure 2. One sampler (Dorset) was electrically heated for winter use and snow samples were thus melted and kept in the liquid state. Rainfall depth was measured at each site using a 10 cm diameter polycarbonate rain gauge. The depth of snowfall was measured in 1978-79 with a Nipher snow gauge. In previous years, snow samples were melted and their volume measured to obtain water equivalent depths of snowfall. All precipitation gauges and collectors were located in cleared areas about 1m above ground (or snow) level. Samples were analyzed for pH and NO_3^{-1} within two days of collection. Analysis of SO_4^{-2} was performed in Toronto within one week of collection. Analytical methods are described in Ontario Ministry of the Environment (1975).

To trace the origin of the air associated with a precipitation event, we have used sea level geostrophic trajectories (Rossby and Egner 1955, Munn and Rodhe 1971, Forland 1973), computed from maps of the surface pressure field. A trajectory segment is derived for each six hourly surface map with the aid of a sea level geostrophic wind scale which provides the length and direction of the trajectory as a function of isobar spacing and orientation. The air parcel is followed back 48 hours in 6 hour increments to its 'octant of origin'. In some cases, the air mass associated with an event remained almost stationary for the 48 hours preceding the event. Such cases were termed 'local'.

Figure 1: Location of Study Area and Collectors. (Numbers refer to Figure 2)

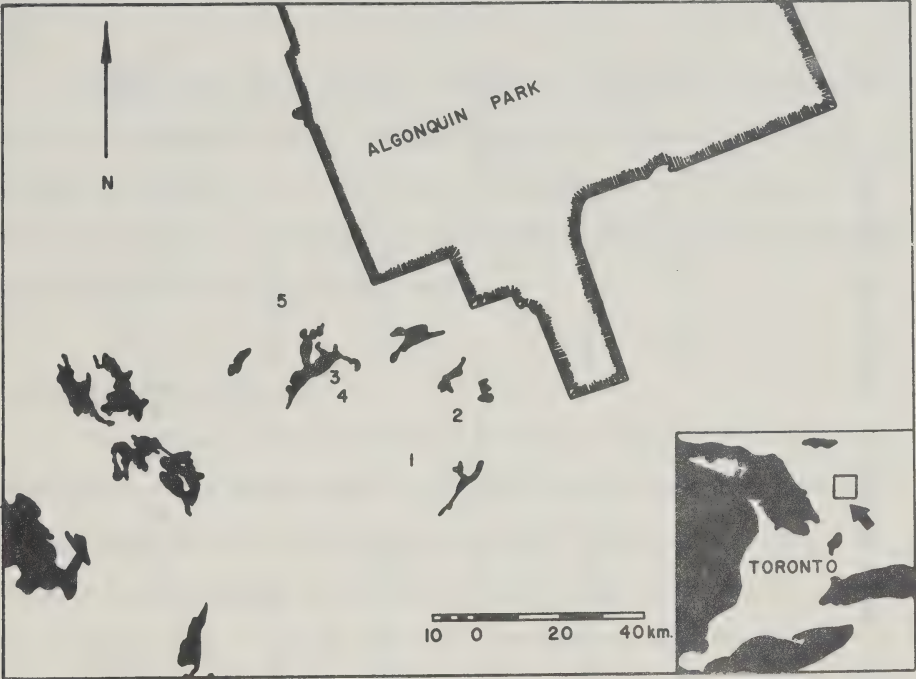
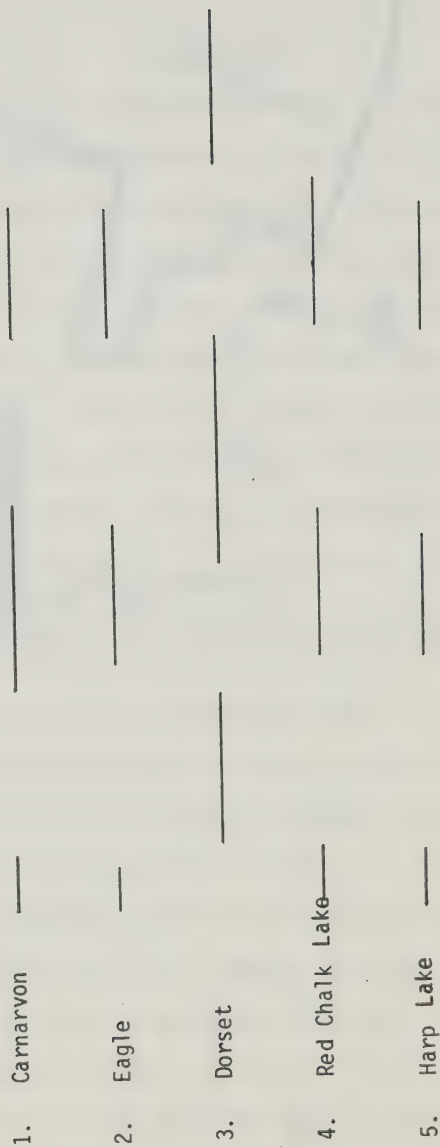


Figure 2: Periods of collector operation. Numbers refer to location on Figure 1.



A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
 1976 1977 1978 1979

The precipitation collectors are part of a network designed with the intent of calculating the bulk and wet deposition of nutrients, ions and heavy metals to lakes in the Muskoka-Haliburton area (Scheider et al. 1979 a, Jeffries and Snyder in press). For this reason, precipitation samples were collected when sufficient volume of sample existed for complete analysis. Depending upon the depth of precipitation in an event, one or several events may have contributed to a single sample.

In this study, we carried out two sets of computations - one for the entire data set (composite sample analysis) and one for samples consisting of a single precipitation event, or several events each associated with the same octant (event sample analysis). A summary of the number of measurements within the composite and event data sets is given in Table 1.

(a) Composite Sample Analysis

The composite data set consists of all data available, including that from composite collections in which several events contributed to the sample. We used these data to make estimates of the maximum possible deposition (of H^+ , SO_4^{-2} and NO_3^{-1}) which could correspond to each octant. Considering each octant in turn, we summed all of the sample loadings associated even partially with that octant. In generating maximum possible deposition we were assuming that events from the octant of interest alone contributed the total load to the sample.

An example may serve to clarify the procedure. Table 2A provides a data sample for the Red Chalk Lake station. To calculate the maximum possible H^+ loadings for each of the octants we get $1983 + 1085 = 3068$ for South, 3315 for South-East, 3315 for South-West, 3315 for North-West and 1085 for North-East (Table 2B). In the analysis, this procedure was applied to the H^+ , SO_4^{-2} and NO_3^{-} data for each station.

TABLE 1: Number of Measurements in Composite and Event Data Sets

<u>Station</u>	<u>Carnarvon</u>	<u>Dorset</u>	<u>Eagle</u>	<u>Harp Lake</u>	<u>Red Chalk Lake</u>
<u>Parameter</u>					
H ⁺ composite	54	56	53	37	40
SO ₄ ⁻² composite	47	34	50	38	34
NO ₃ ⁻¹ composite	40	37	40	38	30
depth-composite	60	58	61	44	43
H ⁺ event	27	24	28	20	18
SO ₄ ⁻² event	29	15	30	21	14
NO ₃ ⁻¹ event	21	16	24	20	11
depth-event	33	26	35	24	18

Table 2A: A data sample for the Red Chalk Lake Station (1978)

Collection Period	Depth (mm)	Sample pH	No. of Events	Octant(s) of origin	H ⁺ load (ueq m ⁻²)
Sept. 11-15	24.4	4.09	2	S, S	1983
Sept. 15-22	43.7	4.12	3	SE,SW,NW	3315
Sept. 22-29	11.1	4.01	2	NE, S	1085

Table 2B: Calculation of Maximum Possible H⁺ Loading for various octants of trajectory origin (based on data from Table 2A)

S	1983 + 1085 = 3068 ueq/m ²
SE	3315
SW	3315
NW	3315
NE	1085

As Figure 2 indicates, sampling at the Dorset station generally covered the cold months ('winter') while precipitation collectors at the remaining sites were made during the warm ('summer') months. We have therefore grouped the data into 'summer' (using the arithmetic mean of loadings at Carnarvon, Eagle Red Chalk Lake and Harp Lake) and 'winter' (using the Dorset loadings).

b) Event Sample Analysis

A second set of computations was based on the 'event' data i.e., those derived from precipitation collections consisting of a single precipitation event, or several events each associated with the same octant of origin. Initially, we computed total event loadings analogous to the composite loadings described above. We then computed weighted average concentrations for each octant and for each ionic constituent. The weighted average concentration is calculated from:

$$W_a = \frac{\sum_{i=1}^n \left(\sum_{j=1}^{m_i} L_{ij} / m_i \right)}{\sum_{i=1}^n \left(\sum_{j=1}^{m_i} d_{ij} / m_i \right)}$$

where: W_a = weighted average concentration for Octant "a"

L_{ij} = loading from collector j for event i

m_i = number of collectors or gauges operating for the i-th event

n = number of events corresponding to Octant "a"

d_{ij} = depth from gauge j for event i

RESULTS AND DISCUSSION

The limitations of this analysis are initially stated. They include:

1. The majority of the precipitation collected is in the form of composite samples i.e., samples comprising two or more precipitation events. The value of such data to trajectory studies is limited (see, for example, Miller et al. 1978).

2. The size of the data set for event samples (i.e., those associated with a single precipitation event) is small. There are, for example, only one 'winter' and one 'summer' event sample corresponding to a trajectory from the northwest sector. The average concentrations associated with the less frequent sectors cannot be considered reliable.
3. The characterization of acidic precipitation events using a single trajectory may be misleading as (a) the storm system involves inflow of air from many directions through convergence in the vicinity of the cyclonic cell, and (b) the mechanism of acidic precipitation formation is a complex amalgam of rainout and washout processes occurring at many atmospheric levels possessing different directions of air flow. Despite these difficulties, some success has been reported from the use of trajectories for tracing source regions (e.g., Forland 1973, Nordo 1975 and Wisniewski 1976).

Table 3 shows the percentage precipitation event samples associated with each octant of trajectory origin as compared with the percentage of composite samples associated with each octant of origin, for the H^+ data set. (The SO_4^{-2} and NO_3^{-1} data sets show qualitatively similar distributions). The Table shows that the South and South-West trajectory directions are more frequent in the event data set while several other trajectory directions are less frequent (particularly East, South-East and North-West). This difference in the frequency distribution results in a corresponding difference in the computed loadings of H^+ , SO_4^{-2} and NO_3^{-1} by octant of origin.

The results of the composite sample analysis (Table 4) show the maximum possible deposition of H^+ , SO_4^{-2} and NO_3^{-1} which could correspond to each octant of trajectory origin. In the case of each of the constituents, and both warm and cold seasons, the South and South-West octants are associated with the greatest

TABLE 3: Percentage of precipitation samples, on which H⁺ analysis was done, associated with each octant of trajectory origin for event and composite data sets

Octant of Origin	<u>Summer*</u>		<u>Winter</u>	
	<u>Event Data (%)</u>	<u>Composite Data (%)</u>	<u>Event Data (%)</u>	<u>Composite Data (%)</u>
NE	5	6	4	7
E	0	4	4	7
SE	0	6	0	8
S	25	19	42	22
SW	46	29	34	24
W	14	13	4	13
NW	2	7	4	9
N	1	3	8	6
Local	7	7	0	4
Number of Samples	18-28	37-54	24	56

* Mean Frequencies for 4 stations are tabulated.

Table 4: Maximum Possible Loadings of H^+ , SO_4^{-2} and NO_3^{-1} ($meq\ m^{-2}$) Associated with Octants of Trajectory Origin (based on composite sampling data, Aug. 1976-April 1979)

		Summer*		Winter	
		(meq/m^2)	(%)	(meq/m^2)	(%)
H^+	NE	4	6	34	32
	E	7	10	28	26
	SE	7	10	16	15
	S	26	37	42	40
	SW	35	50	60	57
	W	15	21	27	25
	NW	10	14	32	30
	N	3	4	4	4
	Local	7	10	13	12
Total**		70	162	106	241
SO_4^{-2}	NE	6	9	14	29
	E	5	7	14	29
	SE	5	7	9	18
	S	23	33	25	51
	SW	34	49	31	63
	W	15	21	15	31
	NW	8	11	12	24
	N	3	4	0.4	1
	Local	10	14	4	8
Total**		70	155	49	254
NO_3^{-1}	NE	2	7	9	30
	E	2	7	9	30
	SE	2	7	4	13
	S	11	38	13	43
	SW	12	41	18	60
	W	6	21	7	23
	NW	3	10	10	33
	N	0.4	1	1	3
	Local	6	21	1	3
Total**		29	153	30	238

*mean of 4 stations

** The total load is not the sum of the individual octant loadings (see text).
Total % figures shown are calculated from total loadings shown.*

maximum possible deposition and the North octant is associated with the lowest maximum possible deposition.

No more than 10% (and likely much less) of the 'summer' deposition of H^+ , SO_4^{-2} and NO_3^{-1} could be associated with any of the N, NE, E and SE octants. From the 'winter' analysis only the North octant was associated with less than 10% of the deposition of each of the constituents. However, the 'winter' figures are less reliable than the 'summer' values because of the greater number of events per collection which is reflected in the larger sum of % values (Table 4).

The results of the event sample analysis (Table 5), although based on a smaller data set, give an estimate of the % of total deposition contributed per octant of origin. In the 'summer' period, events originating in the S and SW octants combined contributed 75% of the H^+ , 70% of the SO_4^{-2} and 57% of the NO_3^{-1} deposition. 'Local' events contributed 10%, 16% and 27% of the H^+ , SO_4^{-2} and NO_3^{-1} respectively. Events originating in the W octant contributed 9%, 8% and 10% of the H^+ , SO_4^{-2} and NO_3^{-1} deposition. Events from all other octants contributed 2% or less per octant of the total deposition. In the 'winter' period, events from S and SW octants again were most important, depositing 85%, 87% and 86% of the H^+ , SO_4^{-2} and NO_3^{-1} respectively. The fraction of the total load deposited by events from the W octant dropped to less than 5% and events from the 'local' sector contributed 0%.

Basically, both data sets show a similar result i.e. that most of the deposition of H^+ , SO_4^{-2} and NO_3^{-1} was probably associated with events originating in the S and SW octants. The W and 'local' sectors were also important contributors to the total deposition in the 'summer' months.

Our results agree with those of Summers and Whelpdale (1976) and Whelpdale (1978) who reported elevated levels of SO_4^{-2} and H^+ in precipitation falling in southern Ontario to be associated with southerly flows of air. Indirect

TABLE 5: Sampled Loadings of H^+ , SO_4^{-2} and NO_3^{-1} ($meq\ m^{-2}$)
 Associated With Octants of 4 Trajectory 3 Origin (based on event sampling
 data, Aug. 1976 - April 1979)

		<u>Summer*</u>		<u>Winter</u>	
		(meq/m^2)	%	(meq/m^2)	%
H^+	NE	0.8	2	1.4	5
	E	0.0	0	0.1	0
	SE	0.0	0	0.0	0

support comes from Lafleur and Whelpdale (1977) and Chung (1978), who concluded from Ontario data that elevated levels of SO_4^{-2} in air measured by high-volume samplers were associated with S-SW air flows. At Ithaca, N.Y. some 350 km south-east of Muskoka-Haliburton, Cogbill and Likens (1974), Dittenhoeffer and Dethier (1976) and Miller et al. (1978) all reported that precipitation originating in the SW sector was the most acidic. Wolff et al. (1979) found for New York, N.Y. that events originating in the W and SW sectors had the lowest pH values. Samson (1978) reported that the highest SO_4^{-2} levels in air collected with high-volume samplers at three locations in New York were associated with air parcels from the SW octant. Many studies point to the highly populated, industrialized S and SW sectors as being the major source areas of polluted air, a reflection of the greater strength of sources in these directions (see, for example, Clark 1978).

Table 6 is a tabulation of weighted average concentrations for H^+ , SO_4^{-2} , and NO_3^{-1} , based on the event data set. Weighted average concentrations serve to characterize the precipitation associated with various source regions. Comments on the Table cannot be too extensive due to the relatively small sample size. For example, the very high average concentrations for H^+ in 'winter' corresponding to E and NW trajectories are based on isolated events. Much more event data are needed before meaningful conclusions can be drawn. It should be noted, however, that a significant concentration of each of the 3 ionic species characterizes precipitation associated with the S, SW, W and NW directions. Note also that the weighted average concentrations in 'summer' are relatively high for 'local' events. This circumstance is possibly due to inflow of air from the Sudbury region (200 km north-west of Muskoka-Haliburton) associated with slow moving storms.

TABLE 6: Weighted Average Concentrations of H^+ , SO_4^{-2} and NO_3^{-1} (ueq/l) (based on event sampling data, Aug. 1976 - April 1979)

		<u>Summer*</u>		<u>Winter</u>	
		ueq/l	number of events	ueq/l	number of events
H^+	NE	36	3	43	1
	E	-	0	204	1
	SE	-	0	-	0
	S	81	11	89	10
	SW	70	18	69	8
	W	101	7	102	1
	NW	106	1	229	1
	N	81	1	17	2
	Local	83	4	-	0
SO_4^{-2}	NE	41	3	21	1
	E	-	0	-	0
	SE	21	1	-	0
	S	81	10	38	4
	SW	93	19	55	7
	W	73	5	63	1
	NW	114	1	23	1
	N	58	1	21	1
	Local	138	4	-	0
NO_3^{-1}	NE	13	2	32	1
	E	-	0	36	1
	SE	6	1	-	0
	S	35	8	30	7
	SW	31	15	48	6
	W	45	5	-	0
	NW	53	1	14	1
	N	29	1	-	0
	Local	91	3	-	0

*mean of 4 stations

CONCLUSIONS

In summary:

- (i) precipitation events most commonly occur with trajectories from the South and South-West octants,
- (ii) an analysis of both composite and event data sets for the 33-month period shows that the majority of H^+ , SO_4^{-2} and NO_3^{-1} deposited at Muskoka-Haliburton is associated with trajectories from the South and South-West, and
- (iii) the average concentrations of H^+ , SO_4^{-2} and NO_3^{-1} in precipitation for the S, SW, W and NW octants are all substantial; precipitation from the remaining octants was very infrequent.

Acknowledgments

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APPENDIX 5

"SATELLITE OBSERVATIONS OF
PERSISTENT POLLUTION EPISODES"

BY

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PRODUCED and NARRATED BY
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The purpose of this tape is to demonstrate the use of conventional meteorological satellites to detect the formation and the spread of large scale pollution episodes sometimes called "smog blobs", "hazy blobs", or "PEPES", that is, Persistent Elevated Pollution Episodes. The Clean Air Act Amendments of 1977 required that the States account for the transboundary movement of air pollution. EPA's environmental sciences research lab has a responsibility to develop models to quantitatively describe this pollution transport. This tape was produced as part of EPA's technical planning for "PEPE 80", an experimental study of long range pollution transport, conducted by the regional field studies office, William E. Wilson, Director.

The opening scene shows the view from atop Whiteface Mountain in the Adirondacks of New York, on the 26th of August, 1977. A beautiful day: with brisk northwest winds, low humidity and a visibility greater than 50 miles. However, from the exact same vantage point, only two days...48 hours later...the visibility had dropped to less than 5 miles after the winds had switched into the southwest. Boundary layer trajectories, calculated by Professor Perry Samson of the University of Michigan, show that on the high visibility day, the air stream had come from Northern Canada. But as changing weather patterns influenced the surface air flow, we can see that the low visibility air was associated with air which had

traveled through Kentucky, Ohio, Pennsylvania, and western New York, into the supposedly rural Adirondacks.

With the passage of The Clean Air Act in 1970, concern centered on large point sources of sulphur dioxide, such as this power plant. Particular interest was paid to the SO₂ impact at ground level within ten or fifteen miles of the source, with respect to The National Ambient Air Quality Standards. But more and more, through the 1970's, research began to demonstrate that pollution can travel far greater distances than we thought. Aside from implied assumptions in the original legislation, air masses certainly travel across air quality control district borders with impunity.

St. Louis, Missouri was the site of Midwest Interstate Sulphate Transport and Transformation Project...MISTT. The plume from a large power plant north of St. Louis on one particular night was found to travel in a cohesive manner as much as three hundred miles (into southern Minnesota). Of course, that plume is surrounded by many smaller sources of sulphur dioxide and other pollutants. On a warm summer day when mixing is significant, these many plumes comingle into what can be termed an "urban plume", which, with a typical southwesterly surface air flow, would drift into Chicago, Milwaukee, and other downstream regions. There are many types of pollutants to be found within a given air stream. Ozone

levels, which may already be elevated during the summer, initially are depleted as the air mass passes through a city such as St. Louis, the result of injections of fresh automobile exhaust. However, the further downwind the air travels, increasing ozone levels are reached attaining a new, higher equilibrium value by the time the airstream passes, in this case, the Chicago metropolitan area. Not only are gases transported these long distances, but visibility reducing aerosols are carried far down wind. While a small fraction of the increased particulate loading is due to the injection of smoke or soot from uncontrolled stacks, the major fraction of it appears to be the result of photochemical conversions within the atmosphere. Essentially, colorless gases, such as sulphur dioxide, emitted into the warm humid summer atmosphere, undergo photochemical conversions (in the presence of strong sunlight). In other words, the gaseous pollutants are converted into Myriads of small particles or aerosols which can include such species as sulphuric acid mist.

This time lapse film shows the sky over the Milwaukee area on a supposedly clear, unpolluted day. But, if you observe carefully, large clouds of aerosols in the lower several thousand feet of the atmosphere are drifting over the city. These do not originate from local sources, but are the result of gases emitted several days upstream which underwent photochemical transformation into aerosols. These chemically, are found largely to consist of sulphates.

Typically, a PEPE occurs when a stagnant summertime high pressure system causes the urban plumes from various cities and major source regions to gradually coalesce and coagulate into one large mass. The regional scale episode can cover many states and extend far out into the Atlantic. Usually a PEPE will persist for several days, and in some cases, for several weeks, until a strong cold front brings clean unpolluted air into the region.

The primary source of these visibility reducing aerosols is apparently sulphur dioxide. The SO_2 largely emanates from coal burning, power plants with tall stacks. Major point sources are scattered throughout the eastern United States with lesser numbers in other parts of the country. But the concentration of major power plants and numerous minor sources in the eastern U.S. is high, not only in the Ohio River Valley, but in a broad belt extending eastward from the Mississippi River through the States of Illinois, Indiana, Ohio, Pennsylvania, and New York. Thus, we would expect to find the maximum sulphate aerosol concentrations and other associated pollutants in this general region.

Now we examine a case study for an August, 1976 episode. Here we see Chicago, where visibilities were restricted for many days running to between 2 to 5 miles. This is not the result of the "Gary Steel Mills" or local sources, but a regional scale episode covering many states. The following is an animation of the

visibilities reported by national weather service stations over a multi-day period extending from the 17th to the 28th of August, 1976. These were reported at noon when fog or morning mist was no longer present. The regions in orange are visibilities of less than 5 miles, with pink less than 3 miles. The low visibility air mass traveled in a cohesive manner for many days. Now, we repeat this animation except that the additional shaded area shows the regions, where the satellite imagery revealed a hazy, turbid air mass. When the haze of a PEPE was detectable in the Goes picture, visibility within these areas was about seven miles or less. Note, at the peak of this episode, on about the 24th of August, the pollution "cloud" stretched from Louisiana, north to Minnesota, and eastward through the Ohio Valley and Mid-Atlantic states, and far out into the Atlantic Ocean. As many as twenty States were engulfed at one time. It took the passage of a strong Pacific cold front through the region to completely purge the eastern United States of this large scale pollution episode. Unfortunately, measurements of sulphate aerosol concentrations are sparse during this time. On the 28th of August, some data were available, and these are plotted. A very strong correlation exists between the sulphate aerosols (as high as 40 and 50 micrograms per cubic meter), the low visibilities, and the milky white haze seen on the satellite photographs.

Thus PEPE's are found to be associated with high concentrations of sulphate aerosols which lower the regional visibility. These, it is assumed, are part of the "raw material" for what is called "acid precipitation". Coincidentally, PEPE's are also associated with major areas of elevated ozone levels. While over the last several decades it is true that average visibilities have actually improved in the center of cities, mean rural visibilities have been steadily decreasing.

What satellites actually "see" is reflected solar radiation. The Goes satellite, perched 22,000 miles above the earth, takes pictures of our planet every 30 minutes. This allows a synoptic view which can be, as in this case, animated to show us the motion of air masses throughout the western hemisphere. The Goes east satellite is one of two observing the United States. A total of five geosynchronous satellites map cloud and aerosol patterns worldwide.

One can appreciate the value of time-lapse satellite images from this sequence showing tornado producing cloud formations over the midwest. The animation reveals the tremendous complexity of atmospheric motions. Air flows at low levels and in the upper atmosphere are really quite different. To predict long range pollution transport, it is necessary to understand the temporal and spatial variability of atmospheric motions. Many times

we can indeed observe aerosol clouds in the atmosphere. This sequence reveals smoke from forest fires north of Los Angeles. A time lapse over a seven hour period shows tremendous quantities of smoke drifting several hundred miles out into the Pacific Ocean in what can certainly be called long range transport. And this smoke clearly has no regard for boundaries of any kind and certainly not air pollution control district borders.

It is really no wonder that the Goes satellite detects these haze-laden air masses. Flying at 10,000 feet above a PEPE in an aircraft, the aerosol concentration below is so dense that the ground is barely visible. Large amounts of the sun's radiation is being reflected back into space, to be monitored by the satellite's sensors. There is considerable promise that a satellite-based system can routinely monitor such large scale pollution movements. But they don't always, however, move from west to east as the textbook might lead us to believe. Of course there is the jet stream, that high speed current of air aloft at approximately 30,000 feet. True enough, it generally flows from west to east. Its main function, as far as we are concerned, is to direct surface weather systems such as high and low pressure systems.

Let's examine a typical migratory high pressure system. The low level airflow travels in an anticyclonic

or clockwise manner. Thus large areas within a high pressure system will experience pollution transport clouds with a component from east to west. Research programs have documented air mass trajectories traveling in a wide variety of directions from Pennsylvania to Florida, from Indiana to Minnesota, and from the Ohio Valley into Canada. In fact, air (and pollutants) on any given day can travel in any particular direction. Therefore, we should rid ourselves of the notion that air only travels from west to east. It may travel north to south, south to north, west to east, or east to west. Thus, one of the major tasks in understanding long range pollution transport is to predict exactly where the air is going with respect to the various emission sources.

In this common type of PEPE episode, air circulates around a high pressure system moving through the Great Lakes. It passes through Pennsylvania, Ohio and West Virginia southwestwards into the lower Mississippi Valley and then makes a curve back through Iowa, Minnesota and into Canada.

A major episode in June and July of 1975 followed this pattern. Computer models have been developed by EPA and its contractors to relate sulphur dioxide emissions and meteorological conditions to resulting sulphate aerosol concentrations. On this particular day, the computer predicted the pattern seen here. A look at an

enhanced satellite photograph taken on this day did indeed reveal a large hazy, milky white cloud of aerosols in roughly the same position as predicted by the computer simulation. Surface visibilities in the hazy region are reduced to 7, and 5, and then 3, and even as low as 2 miles in portions of western Missouri and Iowa, as a result of circulation around the backside of the high pressure system. Peak hourly ozone values over 160 parts per billion were recorded where the diamonds are displayed. The few scattered sulphate reports available at the time once again found the highest concentrations in the low visibility highly ozonated air.

Most revealing perhaps, is an animation of the satellite imagery on this day. We start in the morning and go into the evening, repeating the cycle many times. The high pressure system is centered over the Great Lakes, thus the air flows through the Ohio and Tennessee Valleys roughly from the northeast to the southwest. Clouds of aerosols are drifting, in this case, as far west as central Oklahoma and eastern Kansas. And in this close-up of Missouri, an apparently "clear spot" is drifting southwestward. This appears to be the signature, the "footprint" if you will, of a washout hole, the result of thunderstorms 12 to 24 hours earlier. Falling rain removed large quantities of the sulphate and other aerosols in the polluted layer near the ground. The same process is ongoing at this moment in Louisiana.

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Observe the northern end of this air stream flowing through Iowa and Minnesota. A strong southerly flow of air into the Gopher State produced the highest ozone values ever recorded there. Highly turbid air (visibilities 2-4 miles) are here seen being injected into a large complex of thunderstorms over northern Minnesota. Those aerosols which did not become involved in the precipitation crossed the border into Ontario.

While the chemical and meteorological processes we have witnessed are very complex, even greater difficulties arise as we try to consider the effects of long range pollution transport. What are the impacts on our quality of life, our aquatic resources, and other environmental factors that are clearly of great concern?

Pollutants subject to long range transport, as well as acid rain, have perhaps some demonstrable impact on agricultural and forest resources. Yet to quantify this remains a very difficult task. What are the effects of month after month, year after year of exposure to fine particulates...which include sulphate aerosols...on human health? This is yet another area where more information is needed. What about the possibility of these hazy air masses affecting our weather? This particular hazy band stretches across central Florida, and is here shown computer enhanced. It was sufficiently dense as to reduce solar heating of the ground so that later in the

afternoon, thunderstorms formed over northern and southern Florida, but not beneath the haze region over central Florida. This is a graphic example of inadvertent weather modification.

But, of course, as mentioned before it is acid rain that is of primary concern. In this particular episode in July, 1978, a massive PEPE is seen to stretch from the Appalachians eastward. Thunderstorms along a cold front moving in from the northwest are ingesting this polluted air, and presumably are resulting in acid deposition at the surface. Unfortunately, while the basics of the mechanisms are understood, there is a tremendous amount of detail yet to be learned about wet removal of pollutants. It is a long way from the smoke stack to the rain gage.

How do aerosols seen in the satellite pictures actually become involved in the precipitation mechanisms? Do they form the rain droplets? Are they scavenged by falling rain and snow beneath the clouds? We don't know all of the answers. One thing is certain, however, large numbers of extremely careful precipitation chemistry measurement must be made. We must also better understand the meteorology of long range transport.

Here is, perhaps, one of the most powerful tools in this effort. This is an antenna listening to the Goes

satellite data being transmitted to MC IDAS, (the Man Computer Interactive Data Access System). MC IDAS is located at the University of Wisconsin in Madison. The MC IDAS system constantly ingests Goes satellite data in order to process, enhance, display and animate it. The software, which was developed over a ten year period by the space science engineering center staff, allows the scientist to overlay all available surface and upper air meteorological data on the satellite images in real-time. Thus, the potential exists to routinely monitor the movement of PEPE's.

This is the video display screen of the MC IDAS system. At 2030 Greenwich mean time on 26 August, 1976, the computer overdraws the geographic boundaries. We can see a portion of a large PEPE stretching eastward from the middle Atlantic States into the Atlantic. The MC IDAS system allows us many analysis options for interacting with the raw digital satellite data that created this picture. By measuring the brightness of the air in this hazy region over water, we find seventy to eighty digital brightness counts (scale runs from 1 to 256). The hazy air is as bright as a thin cirrus cloud. But if we go south of the polluted air mass, over the dark water in the high visibility area near Cape Hatteras, we measure only 40 digital brightness counts. The same is true of the relatively clean air just south of Long Island. Thus, the PEPE produces a very distinct

and measureable signature. It is quite possible to make quantitative measurements of the amount of reflected sunlight, and presumably, estimate the total burden of aerosol in the air.

Take this example in May, 1978. A hazy area was detected moving through western Wisconsin and Minnesota, apparently associated with pollution transport. The computer here plots the current temperature, (in centigrade) and we find it to be a moderately cool spring morning. Surface wind stream lines show that a high pressure system in northern Wisconsin is reaching down into the Ohio Valley where presumably the airstream has accumulated air pollutants. These then return northwards in the clockwise circulation, passing through Minnesota and western Wisconsin, and continue northeastwards over Lake Superior. Double checking the 5,000 foot wind field, we find the same cross-Lake Superior air flow is present.

Thus, it is now possible to use satellites to routinely detect areas of low visibility air. In this example the "clean" air over Lake Superior had 15 miles visibility, whereas within the turbid region (portions of Minnesota) it was only three to five miles. Hereafter, fronts can no longer be construed as only discontinuities in temperatures and moisture content, but also, pollution. The satellites are especially useful in tracking polluted air

masses over water - where measurements are scarce or non-existent. The satellite images raise a most intriguing question...just how far can these polluted air masses travel? In this animation sequence, a polluted air stream leaves the middle Atlantic states and travels northeastward, far over the Atlantic ocean. In 1980, during the PEPE program, MC IDAS was able to track one such polluted air mass to at least 40° west longitude...or half the distance to England.

We would like to acknowledge those who have made this tape possible, especially the Environmental Protection Agency/Regional Field Studies Office.

APPENDIX 6

A BRIEF REVIEW OF THE TROPOSPHERIC CHEMISTRY OF SULFUR
DIOXIDE AND THE NITROGEN OXIDES

BY

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(Document prepared for the Ministry of the Environment,
Air Resources Branch, Ontario, Canada under order number
A 70782, Requisition number 99130).

1. Introduction

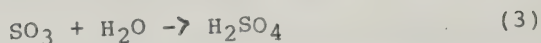
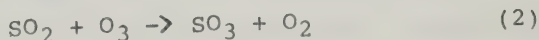
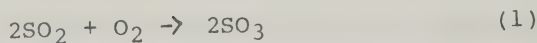
Sulphur dioxide (SO_2) and the nitrogen oxides (nitric oxide, NO ; nitrogen dioxide, NO_2) are relatively reactive gases which are released into the atmosphere by a variety of anthropogenic and natural sources. Interest in these atmospheric impurities has grown in recent years as it became clear that they are oxidized in the atmosphere to sulphuric acid (H_2SO_4) and nitric acid (HNO_3). These strong acids are believed to be largely responsible for the problem of "acid rain" which has been identified in recent years. As a result of very extensive laboratory and field work, a great deal has been learned about the chemical and physical processes which control these transformations. Many of the pathways are homogeneous; that is they occur by reaction between molecular species in the gaseous phase of the atmosphere. Others are heterogeneous in nature in that the gaseous pollutants SO_2 and NO_2 dissolve in rain water, cloud water, surface water, in the solutions of aerosol droplets, or they react on the solid particulate matter present in aerosol form in the atmosphere. Solution phase or surface reactions of SO_2 and NO_2 with other impurities may also result in their oxidation with acid formation.

Abundant evidence shows that both homogeneous and heterogeneous pathways of SO_2 and NO_2 oxidation occur in the atmosphere. The rate and the extent to which they occur and lead to "acid rain" within the environment depend on a great variety of factors, many of which are well understood while others remain unresolved today. In this brief review no attempt could be made to discuss at length or reference all of the very extensive literature which bears on this complex subject. Only those factors which the author feels are key to our understanding of the problem will be discussed here. The equally complex and important problems of quantifying the rates of dry and wet deposition of NO_2 , SO_2 , HNO_3 , and H_2SO_4 , rain out processes, and neutralization of the acids by ammonia (NH_3) and other basic compounds are not considered here. The conclusions concerning the chemistry of "acid rain" formation are necessarily tentative, and they represent the author's evaluation of the vast and often conflicting literature in the area.

2. The Tropospheric Chemistry Which Leads to the
 Homogeneous Oxidation of SO_2

A number of potentially important homogeneous processes for SO_2 atmospheric oxidation which are favored thermodynamically have been found to be extremely slow reactions under uncatalyzed conditions; the reactions of

SO₂ with molecular oxygen (O₂) and ozone (O₃) are in this class.¹



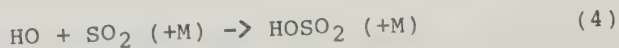
Sulphur dioxide absorbs a significant fraction of the sunlight (wavelengths below 4000 Å) which penetrates into the troposphere. Although the rate of generation of excited electronic states of SO₂ is very significant during daylight hours within the troposphere (rates up to 13%/hr. with the sun directly overhead), the quenching of these non-dissociative excited states of SO₂ by the atmospheric gases leads to very little net oxidation of SO₂. Thus the quenching by molecular oxygen appears to result only in electronic energy transfer with the generation of excited singlet oxygen molecules (¹Σ_g⁺, ¹Δ_g) which are ineffective in oxidizing SO₂ at the atmospheric levels produced in this and other reactions. A variety of extensive laboratory studies show clearly that only a very small fraction of a percent per hour of the total SO₂ impurity present in the atmosphere is oxidized as a result of the photochemical processes initiated by the direct sunlight absorption of SO₂.¹

Laboratory and field experiments have shown that a number of highly reactive, transient species are

generated in a sunlight-irradiated lower troposphere by a complex series of photochemical and thermal reactions which are well characterized. Among these species are many which have the thermodynamic potential of oxidizing SO_2 in the gas phase: excited molecular oxygen, $\text{O}_2(^1\text{g})$, $\text{O}_2(^1\text{g}^+)$; ground state and excited oxygen atoms, $\text{O}(^3\text{p})$ and $\text{O}(^1\text{D})$ respectively; nitrogen trioxide, symmetrical NO_3 and ONOO ; dinitrogen pentoxide, N_2O_5 ; hydroperoxy radical, HO_2 ; alkyl peroxy radicals such as methylperoxy (CH_3O_2), tert-butylperoxy ($\text{t-C}_4\text{H}_9\text{O}_2$), etc.; acylperoxy radicals such as acetyl peroxy (CH_3COO_2); hydroxy radical, OH ; alkoxy radicals such as methoxy (CH_3O), ethoxy ($\text{C}_2\text{H}_5\text{O}$), etc.; Criegee intermediates of the ozone molecule reactions with the alkenes such as CH_2O_2 formed in the $\text{O}_3\text{-C}_2\text{H}_4$ system. The rate constants for the reactions of many of these species with SO_2 have been determined, reasonably accurate estimates can be made of the tropospheric concentrations of these transient species, and the potential significance of certain reactants can be calculated readily. In the most detailed of the current evaluations, Calvert, et al.,¹ concluded from the evidence at hand that the species, $\text{O}_2(^1\text{g})$, $\text{O}_2(^1\text{g}^+)$, $\text{O}(^1\text{D})$, NO_3 , ONOO , N_2O_5 , $\text{t-C}_4\text{H}_9\text{O}_2$, CH_3COO_2 , and CH_3O , have rapid alternative pathways of decay which exclude significant interaction with SO_2 in the ambient troposphere. However, they recognized that several other species could contribute measurably to SO_2

oxidation. These include the species, $O(^3P)$, HO_2 , CH_3O_2 , OH , and CH_2O_2 (and its analogous higher homologues from O_3 reaction with propylene, butenes, etc.). More recent experimental evidence allows a more definitive evaluation of these agents as SO_2 oxidizers.

Recent published results related to the SO_2 system support the view that the OH -radical reaction with SO_2 is the most important homogeneous mechanism of SO_2 removal in the troposphere. In this case the oxidation of SO_2 is initiated by OH -radical addition to SO_2 in the elementary reaction (4):



The subsequent detailed reactions of the $HOSO_2$ -radical product of (4) are open to some question, but there is little doubt that H_2SO_4 will be formed as the major ultimate product following this rate determining step.¹ Laboratory studies have provided us with quantitative measurements of the rate constant, $k_4 = (1.1 \pm 0.3) \times 10^{-12} \text{ cc molec}^{-1}\text{sec}^{-1}$ at 25°C and pressure near 1 atm.^{1,3-7} The reaction has a small negative activation energy ($E_a = -1.5;^7 -2.8 \text{ kcal/mole}^6$), and hence the rate constant increases somewhat with decrease in temperature; for example, at 0°C and 1 atm pressure, $k_4 = (1.5 \pm 0.3) \times 10^{-12} \text{ cc molec}^{-1}\text{sec}^{-1}$. From the existing rate constant

data we can derive the approximate relation (5) for the rate (%/hr) of SO_2 oxidized by the homogeneous reaction (4) in the troposphere:

Rate SO_2

Oxidation in (4) = $(\text{OH}) (1.06 \times 10^{-8} e^{1080/T})$, %/hr. (5)

Here the (OH) is in units of molec/cc. Thus if the (OH) is known the rate of SO_2 oxidation by (4) can be calculated.

The OH-radical concentration in both the clean and the polluted troposphere has been estimated by theoretical and experimental methods. Although the monitoring of the important OH-radical in the troposphere is far from routine today, there is considerable direct evidence which defines reasonably well the magnitude of the tropospheric (OH) under a variety of conditions. Experimental techniques include the methods of chemical reaction using ^{14}C -labeled carbon monoxide,⁸ transmission spectroscopy,⁹⁻¹¹ laser induced fluorescence,^{12,13} and atmospheric removal rates of specific hydrocarbons in the troposphere.¹⁴⁻¹⁸ Theoretical estimates of the OH-radical levels have been made from a variety of computer simulations of the complex chemistry which occurs in both the clean and polluted troposphere.¹⁹ If one discards the early laser fluorescence measurements in which generation of the OH-radicals through ozone

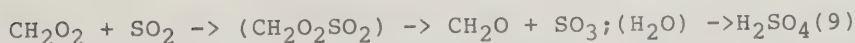
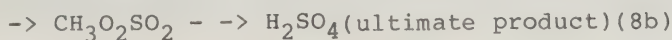
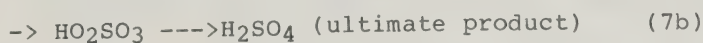
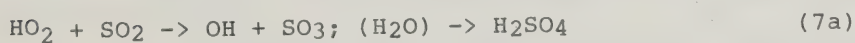
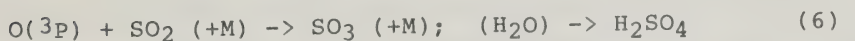
photolysis within the exciting laser beam was significant, all current, limited experimental data are in reasonably good accord with the theoretical models.

Typical values anticipated for (OH) in the hydrocarbon-nitrogen oxide-polluted lower troposphere at 40°N latitude reach a maximum of about 9×10^6 molec/cc for summer noontime, and about 2.4×10^6 in winter. These values are expected to fall with decreasing solar intensity, reaching levels of less than 2×10^5 during the nighttime hours. In rural tropospheric air the (OH) may climb to about 8×10^6 molec/cc at summer midday, 4.2×10^6 in winter, and in each case it falls to low values at night. The (OH) is sensitive to the solar zenith angle (latitude, day of the year, time of the day), temperature, levels of impurities (such as NO, NO₂, hydrocarbons, aldehydes, etc.), and the extent of cloud cover and aerosol attenuation of the solar ultraviolet reaching the parcel of air.

From the "typical" (OH) values cited and the equation (5) we can estimate that SO₂ oxidation rates through reaction (4) alone may be up to 3.6%/hr at the 1200 hour in summer and about 1%/hr in winter, while rates from this reaction are expected to fall below 0.1%/hr during the nighttime hours. Obviously the homogeneous oxidation of SO₂ by reaction (4) can provide

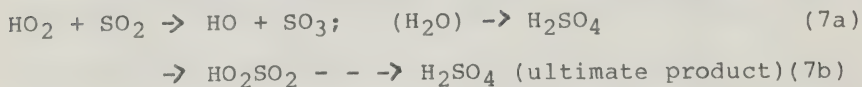
an important contribution to the sulphuric acid formation in the atmosphere.

In addition to the oxidation of SO_2 by OH-radicals, there are several other homogeneous processes which may also contribute measurably to the atmospheric oxidation of SO_2 for certain conditions. These include the following reactions:



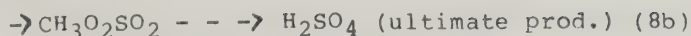
The rate constant k_6 for the $\text{O}(^3\text{P})$ reaction with $\text{M} = \text{N}_2/\text{O}_2$ at 1 atm, 25°C has been evaluated¹ as $(5.7 \pm 0.5) \times 10^{-14}$ cc molec⁻¹sec⁻¹. Reasonably accurate theoretical estimates of $\text{O}(^3\text{P})$ can be derived for various atmospheric conditions from a knowledge of the precursor O_3 and NO_2 molecule concentrations, the quantum efficiencies of O-atom formation as a function of wavelength, wavelength distribution of sunlight within the troposphere, and rate constant estimates for the dominant O-atom reaction, $\text{O} + \text{O}_2 (+\text{M}) \rightarrow \text{O}_3 (+\text{M})$, in the troposphere. These estimates show that usually less than

0.01%/hr. oxidation of SO_2 can occur from reaction (6) for the normal conditions encountered in the lower troposphere. In theory the reaction (6) can provide a burst of SO_3 (H_2SO_4) formation in a sunlight-irradiated plume which is initially rich in NO , NO_2 , and SO_2 . Thus with initial concentrations: $(\text{NO}) = 500\text{ppm}$, $(\text{NO}_2) = 20\text{ppm}$, $(\text{SO}_2) = 500\text{ppm}$, and $(\text{O}_2) = 1 \times 10^5 \text{ ppm}$, the instantaneous rate of SO_2 oxidation by (6)² can be as high as 1.4%/hr.¹ However the rate of (6) falls very quickly as dilution of the plume gases occurs. Thus we can conclude that (6) is not a major source of H_2SO_4 in the troposphere. The latest experimental data^{20,21} related to reaction (7) negate the previous higher estimates for k_7 derived from less direct experiments.²²

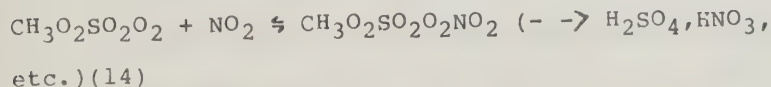
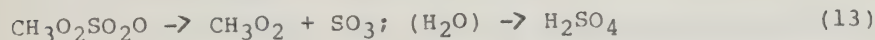
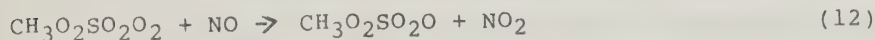
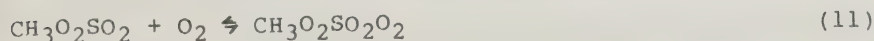
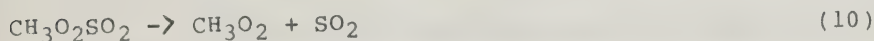


They suggest upper limit values of k_7 2×10^{-17} and $1 \times 10^{-18} \text{ cc molec}^{-1}\text{sec}^{-1}$. It can be shown that for all reasonable conditions encountered in the troposphere the normal (HO_2) is below $6 \times 10^9 \text{ molec/cc}$, and hence the oxidation by (7a) and/or (7b) must be unimportant compared to (4).

Rate constants related to the methylperoxy radical- SO_2 reaction (8) have been the subject of several recent studies.²³⁻²⁵

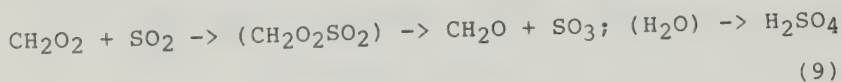


The apparently conflicting results of experiments from flash photolysis and low steady intensities appear to be rationalized well in terms of the occurrence of reaction (8b) with $k_{8b} = (1.4 \pm 0.2) \times 10^{-14} \text{ cc molec}^{-1}\text{sec}^{-1}$ at 25°C. However regeneration of the CH_3O_2 radicals may occur in (10) or, in the presence of NO and NO_2 competitive reactions (12)-(14) can lead ultimately to acid formation:

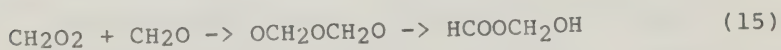


The extent to which CH_3O_2 leads to the net oxidation of SO_2 is expected to be a complex function of the concentration of peroxy radicals, SO_2 , NO, NO_2 and possibly other impurity species. At this writing a quantitative evaluation of the rate constants for the competitive reactions for $\text{CH}_3\text{O}_2\text{SO}_2$ is not available. For the purposes of our discussion here, we cannot establish the importance or unimportance of the SO_2 oxidation by CH_3O_2 in an NO_x -hydrocarbon-polluted atmosphere, but further kinetic information is required to evaluate its role.

There is abundant evidence that the Criegee intermediate involved in O₃-alkene reactions (e.g., CH₂O₂ from O₃ plus C₂H₄) oxidize SO₂ readily, presumably in reaction (9):26-28



In both the urban and rural atmospheres the rate of generation of these reactive species, CH₂O₂, CH₃CHO₂, etc., from O₃-alkene reactions can be very significant, and the fraction of the CH₂O₂ which survive decomposition to react with impurity molecules is relatively large (about 37%). However experiments have shown that competitive reactions of the CH₂O₂ species occur with other impurities often present in the lower troposphere (e.g., CH₂O, CH₃CHO, etc.), and reaction with NO seems likely as well.^{28b}



Present data show that when the (CH₂O)/(SO₂) ratio is less than about 4 then reaction (9) is favored over (15). However the ratio of k₁₆/k₉ is unknown today, so the rate of CH₂O₂ oxidation of SO₂ in the NO-polluted troposphere cannot be estimated. It seems probable to the author that reaction (9) does occur significantly, especially in aged air in which the (NO)/(NO₂) ratio

and/or the NO concentration is very small. Obviously dark reactions of O_3 with the alkenes will continue to occur during the nighttime hours, and SO_2 oxidation by the homogeneous process (9) can continue as a unique route to H_2SO_4 when (4), (6), and (8) have practically ceased to occur in the absence of sunlight generation of the HO , $O(^3P)$, and CH_3O_2 radicals.

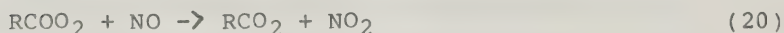
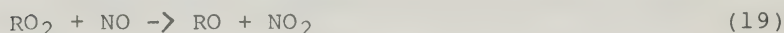
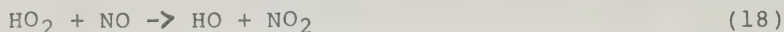
In summary the minimum rate of SO_2 oxidation by homogeneous gas phase reactions can be derived well from our current knowledge of the reaction rate constant for reaction (4) and the OH -radical concentration in the troposphere estimated both experimentally and theoretically. These minimum rates of SO_2 oxidation to H_2SO_4 amount to about 1 to 3.6%/hr for noontime during winter and summer, respectively. The rates track the solar intensity roughly, falling to near zero at night. However additional SO_2 oxidation by CH_3O_2 , CH_2O_2 (CH_3CHO_2 , etc.) may add other pathways for SO_2 conversion to H_2SO_4 ; these cannot be evaluated quantitatively at this time.

3. The Homogeneous Oxidation of NO and NO₂ in the Troposphere

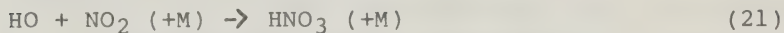
The conversion of NO to NO_2 in the troposphere is relatively slow by way of the termolecular reaction (17) when NO is in the ppm concentration range.



However during the early stages of dilution of an auto exhaust or a stack gas rich in NO (about 500 ppm), the reaction (17) can convert NO to NO₂ at a rate as high as 15%/minute.^{19h} Oxidation of NO to NO₂ proceeds rapidly in a sunlight-irradiated NO_x-hydrocarbon-polluted troposphere as a result of the reaction of hydroperoxy (HO₂), alkylperoxy (RO₂), and acylperoxy (RCOO₂) radicals formed in a complex series of reactions.¹⁹



The dominant homogeneous reaction of NO₂ in the troposphere is that with the OH-radical:



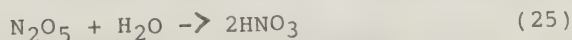
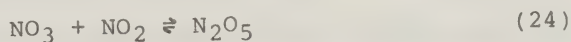
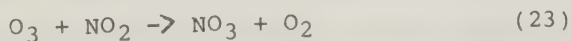
This leads to the strong acid, nitric acid (HNO₃). The rate constant for (21) is significantly larger than that for (4) involving SO₂ and OH; recent data suggest $k_{21} = (1.2 \pm 0.1) \times 10^{-11} (T/298)^{-1.6}$ for M = N₂/O₂ near 1 atm.²⁹⁻³¹ The rate of conversion of NO₂ to HONO₂ in (21) is fast for the common OH-radical concentrations encountered in the troposphere. Using the rate constant data referenced above, we derive the useful relation (22):

Rate NO₂ Oxidation

$$\text{in (21)} = (\text{OH}) (4.3 \times 10^{-6} (\text{T}/298)^{-1.6}), \text{ \%/hr. (22)}$$

Here (OH) is again in molec/cc units. Thus maximum rates typical for the polluted troposphere at noon time (40°N latitude) are about 39%/hr in summertime and 10%/hr in winter. For the rural lower troposphere at noon about 34%/hr is expected in summer and about 18%/hr in winter. As with the SO₂, one can anticipate that the NO₂ rates in (21) will drop precipitously during nighttime hours and follow roughly the (OH) variation with change in solar intensity during the daylight hours.

The homogeneous formation of HNO₃ through the reaction sequence involving O₃, NO₂, and N₂O₅ (reactions 23-25) is expected to be less important than that produced in (21), since N₂O₅ levels are normally very low and the homogeneous reaction (25) is very slow.³²



4. The Heterogeneous Pathways of SO₂ Oxidation in the Troposphere

A variety of evidence supports the current consensus that heterogeneous processes involving SO₂ may also be

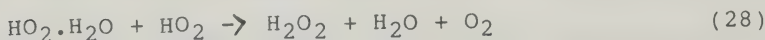
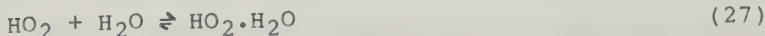
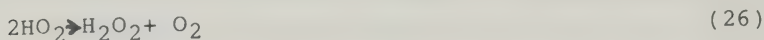
important pathways leading to H_2SO_4 formation. For example, the very high rates of conversion of SO_2 which have been observed in some field measurements cannot be explained by the recognized homogeneous chemistry alone. Also the ^{18}O -content of the atmospheric sulphate (aerosols and rain water) suggests that heterogeneous oxidation of SO_2 in the liquid phase may be the dominant sulphate forming mechanism associated with precipitation.⁵⁸ Laboratory studies over several decades show clearly that the oxidation of SO_2 to form the sulphite ion can occur in the liquid phase by several reasonable and seemingly important processes involving O_2 , O_3 , and H_2O_2 as oxidizing agents. Penkett, et al.³³ concluded from their studies and a review of the literature on these systems that H_2O_2 may be the most important oxidizing agent for sulphite ion-containing droplets of cloud water or rain water in the atmosphere. Gas phase concentrations of H_2O_2 of several ppb and H_2O_2 concentrations in rain water of several hundred ppb have been observed.³⁴⁻³⁷ The very high Henry's law constant for H_2O_2 in water is consistent with the observed buildup of H_2O_2 in the aqueous phase. There are recent rate data on the H_2O_2 -sulphite ion system from several sources.^{33,38-40} Illustrative calculations using these data³⁹ show that for a cloud containing gaseous SO_2 at the 5 ppb level, gaseous H_2O_2 at 1 ppb, and 0.3 ml of water per m^3 , a relatively enormous rate of sulphite

oxidation (2.6%/min) is anticipated. For such conditions the rate of reaction in a cloud or fog can be limited by the rate at which SO_2 can dissolve into the water droplets. For a typical droplet radius of 10 microns for the conditions cited above, the conversion rate was estimated to be about 2.1% per min. Obviously if H_2O_2 is commonly present at levels seen in some cases, then this pathway to H_2SO_4 generation can be very important in droplets.

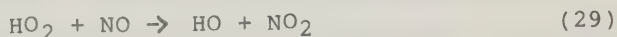
A combination of lower Henry's law constants for O_2 and O_3 in H_2O , the lower rate constants for their oxidation of sulphite ion, and the inhibition of the reaction by acid product formation, leads to a less important role than that for H_2O_2 for these reactants in the atmosphere. However under certain conditions O_3 at common ambient levels can be a significant reactant for sulphite oxidation in solution.³³

It is not possible at this time to define meaningful quantitative relationships from which we might estimate the rate of SO_2 transformation to H_2SO_4 by these heterogeneous processes in cloud or rain water; our knowledge of the H_2O_2 concentration and its distribution in air masses and cloud water is very incomplete today. However the presence of H_2O_2 in the atmosphere is both observed experimentally and expected theoretically. It is well established that H_2O_2 is a product of the

homogeneous disproportionation reaction between HO₂ radicals, reaction (26), and the hydrated HO₂ radical, reaction (28):⁴¹⁻⁴⁶



Other sources of H₂O₂ in the atmosphere can be suggested as well, but there is little evidence to firm up the significance of these alternative pathways. Simulations show that the reactions (26) and (28) can provide the bulk of the H₂O₂ seen in the atmosphere. The precursor HO₂ radical is generated in sunlight-irradiated rural and polluted urban atmospheres in a series of reactions involving hydrocarbons and alkoxy radicals derived from them. The HO₂ radical reaction with NO in (29) dominates over its reactions (26) and (28) in atmospheres highly polluted with NO.



However in aged "smog" or polluted air masses in which NO is largely converted to NO₂, H₂O₂ formation in (26) and (28) becomes a major sink for the HO₂ radical, and significant H₂O₂ product is expected.¹⁹ⁱ In this case we see an important reactant for the liquid phase heterogeneous oxidation of SO₂ is controlled by

homogeneous gas phase reactions which are themselves very dependent on solar intensity, water vapor content, and various pollutant concentrations (NO , NO_2 , hydrocarbons, aldehydes, O_3 , etc.).

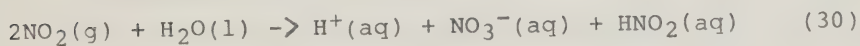
The uncatalyzed liquid phase oxidation of SO_2 by molecular oxygen (O_2) appears to be non-competitive with those involving H_2O_2 and O_3 , although some scientists conclude that it is important in neutral and weakly acidic solutions sometimes encountered in the atmosphere.^{47,59i,60} In any case the metal catalyzed solution phase oxidation of sulphite by atmospheric O_2 can contribute to sulphuric acid formation under certain circumstances.⁴⁸ For example, the strongest correlation with measured rates of oxidation of sulphite in rain water samples collected in England was found between the concentration of dissolved manganese salt in the samples. It appears to this author that the ion-catalyzed solution phase oxidation of SO_2 may be less important generally than solution phase oxidation by H_2O_2 and O_3 , although peculiar circumstances (e.g., near stack sources, absence of efficient particulate removal equipment at the source) which enhance the metal ion concentration in emissions, may lead to significant oxidation by this pathway, particularly in the early stages of plume dilution and under conditions of high humidity.

Laboratory experiments have shown that sulphur dioxide atmospheric oxidation may be catalyzed on a variety of solid substrates, including fly ash, dust, pure metal salts, and carbonaceous materials. The catalytic properties of combustion-produced soot (carbonaceous) particles for SO_2 oxidation has been found to be enhanced in the presence of liquid water,⁴⁹ and it has been claimed that atmospheric SO_2 oxidation through the reaction on carbonaceous aerosols can be a major contributor to atmospheric sulphate levels.⁵⁰

Unfortunately the significance of the gas-liquid and gas-solid phase systems involving SO_2 oxidation are very difficult to treat quantitatively in atmospheric modelling in that the exact nature of the aerosol reactants is usually not known, and the reactions are often sensitive to changes in surface and bulk composition, acid formation, inhibition by certain atmospheric impurities, etc. However, realistic attempts to include such reactions in atmospheric modelling efforts will be required in order to properly rationalize acid formation rates under conditions of high aerosol loading, high humidity, in cloud water, rain water, and during the nighttime hours.

5. The Possible Heterogeneous Involvement of the
Oxides of Nitrogen in Acid Formation in the
Atmosphere.

There are strong indications that nitrate formation in atmospheric aerosols may involve some heterogeneous reactions of the oxides of nitrogen. One cannot discount HNO_3 formation from the homogeneous pathway, reaction (21), but the incorporation of gaseous HNO_3 into aerosols composed largely of H_2SO_4 solutions requires the formation of NH_4NO_3 (significant NH_3 level required) or some other less volatile or more stable salt. Thus Orel and Seinfeld⁵¹ found that theoretical equilibrium values of nitrate in aqueous solution in the presence of sodium chloride, nitric oxide, nitrogen dioxide, sulphur dioxide, carbon dioxide, ammonia, and sulphuric acid (at typical urban levels) are of the order of those observed in urban atmospheres. The reaction (30) was thought to be the major route to nitrate aerosol generation:



Recently Lee and Schwartz⁵² have measured the rate constants for reaction (second order in NO_2) under conditions applicable to the atmosphere, and the results show that nitric acid from this source could be significant.

There are a number of studies in which an evaluation of the effect of NO, NO₂, HNO₂, and HNO₃ on the heterogeneous oxidation of SO₂ was made. Durham, et al.,⁵³ have concluded from a simulation of below cloud rain events that gaseous nitric acid may control acidification in the early stages of the event. The HNO₃ is removed from the atmosphere by rain water much more rapidly than is SO₂. It may inhibit SO₂ oxidation by O₃ in rain droplets, although oxidation by H₂O₂ is much less affected. They concluded that the reaction (30) was not an important source of HNO₃ in a subcloud scavenging rain event. Numerous other recent experimental studies point to the potential role of NO, NO₂, and HNO₃ on SO₂ oxidation on carbon particles.⁵⁴ N₂O appears to be one of the products of this system which may be derived from further reactions of a primary product, hydroxylamine disulfonate. Nitrite and sulphite ions react in solution to give this product.⁵⁵ NO₂ on carbon surfaces can also act to oxidize SO₂, presumably through the net reaction, NO₂ + SO₂ -> NO + SO₃.^{54a,54b} Active site poisoning was seen at high reactant concentrations.

Barbaray and co-workers⁵⁶ have reported the NO₂-H₂O-enhancement of SO₂ oxidation on V₂O₅ particles. Nash⁵⁷ found that NO₂ added to solutions of transition metal ions enhanced sulphite oxidation rates. These observations are by no means exhaustive, but they should

serve to illustrate the extreme complexity and the seeming importance of heterogeneous reactions leading to the oxidation of the oxides of nitrogen, and synergistic effects of NO_x addition on heterogeneous SO_2 oxidation systems may be common.

6. Summary

There can be no doubt today that the atmospheric chemistry of SO_2 , NO , and NO_2 results in the generation of sulphuric and nitric acids in the environment. The fraction of this conversion which occurs by homogeneous and heterogeneous processes remains unclear today. It can be well demonstrated that the homogeneous oxidation of both SO_2 and NO_2 by OH-radicals occurs at significant, theoretically predictable rates during the sunlight hours within the troposphere. Other homogeneous processes involving $\text{O}(^3\text{P})$, CH_3O_2 , and Criegee intermediates such as CH_2O_2 may also contribute significantly for certain conditions; see sections B and C. The observed rates of transformation of SO_2 to sulphate aerosol within well-defined power plant and smelter plumes are often in the range 0.2-4%/hr.⁵⁹ These rates are of the magnitude of those anticipated theoretically from the occurrence of the homogeneous, OH-radical mechanism of SO_2 oxidation alone. However much other laboratory and field data point to the significant participation of heterogeneous

oxidation pathways for SO_2 oxidation processes, particularly in cloud and rain water and in atmospheres with heavy aerosol loading. Of probable major importance are the pathways involving SO_2 absorption into cloud water and rain water with subsequent liquid phase oxidation by H_2O_2 , O_3 , and possibly O_2 (metal ion catalyzed).

The task of complete simulation of sulphuric and nitric acid development in a dynamic, real tropospheric air mass is a very difficult one. Unfortunately the known mechanisms of both the homogeneous and heterogeneous reaction pathways of SO_2 and NO_2 oxidation in the atmosphere exclude as a reasonable practice the use of first order conversion terms to describe these complex chemical processes. However, in some models of atmospheric transport and transformation in use today such a highly simplified procedure has been adopted to save computational time. It should be noted that the known homogeneous and heterogeneous processes which lead to sulphuric acid and nitric acid formation are not dependent on SO_2 or NO_2 concentrations alone, but they are dependent on many other reactant concentrations in a complex fashion. Thus the OH-radical concentration which seemingly determines the bulk of the SO_2 and NO_2 homogeneous oxidation rates and also indirectly affects the heterogeneous SO_2 oxidation reactions involving H_2O_2

and O_3 , is a complex function of many trace reactant concentrations including hydrocarbons, NO , NO_2 , aldehydes, etc., as well as the solar intensity. Only if the OH concentration were constant during the day and night would a first order homogeneous conversion rate of SO_2 result. In so far as reasonable estimates of the OH -radical concentration can be made in a transported air mass, then reasonably accurate rates of formation of H_2SO_4 and HNO_3 through (4) and (21), respectively, can be made. Until such time that more definitive experimental and theoretical treatments of the heterogeneous pathways can be made, it will be necessary to use some form of empirical parameterization of these processes in modelling attempts. Such methods cannot be of lasting value, and predictions based upon them will necessarily be of uncertain usefulness in development of predictive models and control strategies for "acid rain".

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APPENDIX 7

Ontario Ministry of the Environment
Air Resources Branch

"DESCRIPTION OF MOE STATISTICAL
LONG RONGE TRANSPORT MODEL"

DESCRIPTION OF MOE STATISTICAL LONG RANGE TRANSPORT MODEL.

1. INTRODUCTION

This chapter describes a simple model used by MOE to provide acceptable estimates of long-term SO_2 and SO_4 concentrations associated with long-range transport. Using a numerically efficient statistical model Fisher (1978) has been able to compute sulfur deposition rates which are comparable to those obtained from models such as that developed by Eliassen (1978; see also Johnson et al., 1978) which require considerably more data input as well as computational effort. In a recent paper, Fay and Rosenzweig (1980) have shown that a simple analytical model based on the two-dimensional diffusion equation is capable of yielding SO_2 and SO_4 concentration estimates which compare rather well with measurements made over the United States. Thus, there is empirical evidence that simple models "work". The long-range transport model presented here is based on this idea. It incorporates useful features which represent improvements over earlier work.

The model is statistical in the sense that the physics of transport is parameterized in terms of statistical parameters. The basic premise of this class of models is that long-term concentrations are insensitive to short-term fluctuations in meteorology. It is assumed that concentrations averaged over periods of the order of a year reflect "mean" patterns of the large scale meteorology. This allows us to take a simple approach to the modeling of long-range transport.

The model described here consists of two components, namely the scavenging and the dispersion submodels, each of which will be described separately. Then we will demonstrate the use of the model by comparing sulfur deposition estimates with measurements presented by Galloway and Whelpdale (1980).

2. SCAVENGING

The treatment of the removal of sulfur is similar to that proposed by Rodhe and Grandell (1972) and used by Bolin and Persson (1975) and more recently by Fisher (1978). However, the submodel is more "physically" based and it will be seen that it is capable of handling more general physical situations than those by the model of Rodhe and Grandell (1972).

The model is based on the idea of classifying pollutant particles as "wet" and "dry". Wet particles exist during precipitation and dry particles during dry periods. On a long term, every travel time from a source is associated with a certain amount of dry particles and a certain amount of wet particles. Using this concept differential equations for the evolution of these particles as a function of travel time from the source are formulated. Before doing so, a few concepts will be clarified. Wet particles, released during precipitation, retain their identity until they encounter a dry period. Following Rodhe and Grandell (1972) it is assumed that the average rate of "conversion" from wet to dry particles is inversely proportional to the average length of wet periods in a Lagrangian sense. A similar assumption can be made regarding "conversion" of dry particles to wet particles. Further, it is assumed that the scavenging coefficients do not vary with travel time. However, they are different for wet

and dry periods. If SO_2 is denoted by G and SO_4 by S, their evolution can be

conveniently shown in Fig. 1. In the figure, λ refers to the SO_2 scavenging coefficient, k is the SO_2 to SO_4 conversion rate, $\bar{\lambda}$ is the SO_4 scavenging coefficient, τ is the average length of wet or dry periods, and subscripts 'd' and 'w' refer to dry and wet particles. It is seen that the 'species' G_d (dry SO_2) is depleted through wet (λ_w) and dry deposition (λ_d), conversion to sulfate (k_d) and conversion to wet SO_2 ($1/\tau_d$). We also note that wet SO_2 is converted to dry SO_2 at a rate given by ($1/\tau_w$). The evolution of sulfate as a function of travel time is modeled in a similar manner. It is important to note that the particular form of the conversion from dry to wet particles or vice versa is based on the assumption that the cumulative frequency distribution of wet or dry periods is exponential (Rodhe and Grandell, 1972). From the diagram the equations for G and S are given as follows:

$$\frac{dG_d}{dt} = -\lambda_d G_d - k_d G_d - \frac{1}{\tau_d} G_d + \frac{1}{\tau_w} G_w \quad (1a)$$

$$\frac{dG_w}{dt} = -\lambda_w G_w - k_w G_w - \frac{1}{\tau_w} G_w + \frac{1}{\tau_d} G_d \quad (1b)$$

$$\frac{dS_d}{dt} = -\bar{\lambda}_d S_d + \bar{k}_d G_d - \frac{1}{\tau_d} S_d + \frac{1}{\tau_w} S_w \quad (2a)$$

$$\frac{dS_w}{dt} = -\bar{\lambda}_w S_w + \bar{k}_w G_w - \frac{1}{\tau_w} S_w + \frac{1}{\tau_d} S_d \quad (2b)$$

If Q_{SO_2} and Q_{SO_4} denote the amount of SO_2 and SO_4 released at the source we can write.

$$G_d(0) = f_d Q_{SO_2}; \quad G_w(0) = f_w Q_{SO_2} \quad (3a)$$

$$S_d(0) = f_d Q_{SO_4}; \quad S_w(0) = f_w Q_{SO_4} \quad (3b)$$

In (3), f_d and f_w are the fractional dry and wet periods at the release point. With (3) the solutions of (1) and (2) readily follow

$$G_d = \sum_{i=1}^2 A_{di} e^{\alpha_i t}; \quad G_w = \sum_{i=1}^2 A_{wi} e^{\alpha_i t} \quad (4a)$$

$$S_d = \sum_{i=1}^2 B_{di} e^{\gamma_i t} + \sum_{i=1}^2 \beta_{di} e^{\alpha_i t}; \quad (4b)$$

$$S_w = \sum_{i=1}^2 B_{wi} e^{\gamma_i t} + \sum_{i=1}^2 \beta_{wi} e^{\alpha_i t}$$

Details of the solution are given in appendix.

F. B. Smith (1980) has developed a scavenging model based on equations almost identical to 1-4. In his paper he provides considerable physical insight into the meaning of wet and dry periods which determine the particle "type" as used in our model. He also considers the effect of the variation of rainfall rates on the evolution of G and S. The significant conclusion of his study is that it is necessary to differentiate between mobile wet and dry synoptic regions in order to make realistic estimates of sulfur deposition.

The formulation of the model enables one to specify different removal rates for dry and wet periods. This can be useful in sensitivity studies. For example, it is easy to test the recent hypothesis (McNaughton and Scott, 1980) that the SO_2 to SO_4 conversion rate is higher during rain than during dry periods.

3. DISPERSION MODEL

The long-term concentration $C(r,t)$ at point r at time t can be written as (Lamb, 1980)

$$\bar{C}(r,t) = Q \int_{-\infty}^t p(r,t|r_s,t') dt' \quad (5)$$

where Q is the emission rate of the source located at r_s and $p(r,t|r_s,t')$ is the probability density that a particle released at r_s at time t' will be found at r at time t . If it is assumed that p can be expressed as

$$p(r,t|r_s,t') = p(r|r_s;t-t') \quad (6)$$

$$\bar{C}(\underline{r}) = Q \int_0^{\infty} P(\underline{r}|\underline{r}_s; \tau) d\tau \quad (7)$$

Note that τ is the time of travel between \underline{r} and \underline{r}_s . To proceed further it is assumed that scavenging and dispersion are independent. Fisher (1978) and Bolin and Persson (1975) have used this assumption in their models. This then allows one to express p as

$$P(\underline{r}|\underline{r}_s; \tau) = M(\tau)D(\underline{r}|\underline{r}_s; \tau) \quad (8)$$

where $M(\tau)$ depends only on removal mechanisms and $D(\underline{r}|\underline{r}_s; \tau)$ is a function of large scale dispersion. It is easy to see that $M(\tau)$ corresponds to the functions G_d , G_w , S_d and S_w (See Eq.4) for unit release and is essentially the probability that a particle will survive after a travel time τ .

The dispersion function $D(\underline{r}|\underline{r}_s; \tau)$ will depend on large scale wind patterns. Bolin and Persson (1975) and Shieh (1977) have shown that the Gaussian puff equation is appropriate here

$$D(\underline{r}|\underline{r}_s; \tau) = f(z, \tau) \frac{1}{2\pi \sigma_x \sigma_y} \exp \left[-\frac{(x-\bar{x})^2}{2\sigma_x^2} - \frac{(y-\bar{y})^2}{2\sigma_y^2} \right] \quad (9)$$

where $f(z, \tau)$ describes the vertical dispersion. The parameters of the distribution $\bar{x}(\tau)$, $\bar{y}(\tau)$ are the co-ordinates of the mean particle position after travel time τ from the release point. The dispersion parameters $\sigma_x(\tau)$ and $\sigma_y(\tau)$ correspond to standard deviations of particles about (\bar{x}, \bar{y}) after travel time from the source. These parameters can be determined from trajectory statistics as suggested by Bolin and Persson (1975).

5. EMISSION INVENTORY

Figure 2 depicts the distribution and relative magnitude of the points which

comprise the sulfur oxides in this study. The emission data for the model was collected from several sources. In the northeastern sector of the U. S. it was compiled from the EPA point source inventories (Benkowitz; 1979) and the GCA (consulting company contracted by EPRI) major point and area source records. The Canadian emission points except in Ontario were taken from the AES preliminary point and area source inventory (Voldner et al., 1980). The Ontario points were extracted from the Ontario Ministry of the Environment sulfur emissions inventory.

To limit the required computational resources, when feasible, sources are lumped together. All large ($>100 \text{ kTonnes SO}_2 \text{ a}^{-1}$) point sources listed in the above mentioned emissions data and 95% of the major ($>10 \text{ kTonnes SO}_2 \text{ a}^{-1}$) point sources are incorporated into the model's inventory (usually grouped) to form effective point sources located at the emissions-weighted geometric means of the co-ordinates of the contributing points. Care is taken to amalgamate only sources situated in similar geographic settings and, in general, less than 50 km apart. Approximately 60% of all area emissions and 72% of all minor point emissions are incorporated into the inventory shown in Figure 2 by adding minor point sources and area sources located near ($\approx 50 \text{ km}$) major points to that point or combining small sources concentrated in large urban centers to form effective point sources.

6. SPECIFICATION OF DISPERSION PARAMETERS

The wet and dry deposition of sulfur depends on the vertical distribution of the pollutant as well as the turbulence in the diurnally varying planetary boundary layer. These factors have to be accounted for in modeling deposition and concentration fields averaged over time scales of the order of a day.

However, Maul (1980) shows that estimates of annual averages of these variables are relatively insensitive to the details of the vertical concentration distribution. Furthermore, Eliassen and Saltbones (1975) and Johnson et al. (1978) have successfully predicted long-term averages, assuming that sulfur is well-mixed through a boundary layer which is invariant in space and time. On the basis of these studies the distribution of SO_2 and SO_4 are assumed to be uniform in the vertical through the depth of a constant mixed layer. This limits the resolution of the model to distances of the order of 100 km from major sources.

The large scale horizontal distribution of pollutants is determined by the parameters \bar{x} , \bar{y} , σ_x and σ_y . For the co-ordinates of the mean motion of large scale eddies it is assumed that,

$$\begin{aligned}x &= u \tau \\y &= 0\end{aligned}\tag{10}$$

where u is the mean velocity of synoptic eddies and τ the travel time from the source. Equation (13) expresses the fact that at mid-latitudes weather systems move from the west to the east. Fay and Rosenzweig (1980) have used this assumption in their modeling exercise.

The analysis of trajectories by Slinn et al. (1979) and Bolin and Persson (1979) suggests that σ_x σ_y can be expressed as

$$\begin{aligned}\sigma_x &= \sigma_u \tau \\ \sigma_y &= \sigma_v \tau\end{aligned}\tag{11}$$

On the basis of statistical dispersion theory it is reasonable to assume that σ_u and σ_v are the standard deviations of the horizontal velocity fluctuations of synoptic turbulence. These statistics could be derived by sampling 850 mb winds over periods of the order of years. Tennekes (1977) suggests the following values for the large-scale velocities

$$u = 10 \text{ ms}^{-1}, \sigma_u = 10 \text{ ms}^{-1}, \sigma_v = 6 \text{ ms}^{-1}$$

It is noted that this choice of the horizontal dispersion parameters is tentative. They will be modified when a statistical analysis of trajectories, has been completed.

SCAVENGING PARAMETERS

The stochastic scavenging model allows one to distinguish between wet and dry periods. This, seen later, is a useful feature of the long-range transport model presented here.

The transformation of SO_2 to SO_4 is a complex process which depends on a number of physics variables such as solar intensity and ambient ozone concentration, (see Wilson and Gillani, 1979). For long-term modeling it is assumed that the conversion rate is 1%/hr, a value which is an "average" of field measurements made during dry periods.

Knowledge of the conversion of SO_2 to SO_4 during rain is almost non-existent. There is some indirect evidence (McNaughton and Scott, 1980; Scott, 1980; MacCracken, 1978) to indicate that incloud conversion of SO_2 to SO_4 can be greater than 10%/hr. Scott (1980) suggests that more than 60% of the sulfur in rain falling in summer is associated with SO_2 . Then it is reasonable to assume

that the rate at which SO_2 appears as sulfur in rain is limited by the rate at which SO_2 is incorporated into precipitating clouds. The rate at which clouds suck up the SO_2 is approximately given by w/z_1 where w is the mean updraft velocity at cloud base and z_1 is the mixed layer height. w is given by (Smith and Hunt, 1979).

$$w = \rho_w R/M \quad (12)$$

In (4), ρ_w is the density of water, R the precipitation rate and M the water content of the air entrained into clouds. Typical values for these variables are $M=5 - 10 \text{ gm}^{-3}$, $R= 1 \text{ mm/hr}$ and $z_1= 1000 \text{ m}$. We then find that the "effective" washout rate w/z_1 for SO_2 is $3-6 \times 10^{-5} \text{ s}^{-1}$. This suggests that one way of accounting for incloud oxidation of SO_2 to SO_4 is to add an effective washout rate to the actual wet removal rate of SO_2 . An alternative is to increase the oxidation rate during precipitation. McNaughton and Scott (1980) found that a 10%/hr rate was necessary to explain measurements of sulfur in rain.

Washout of SO_2 is a reversible process which is a function of pH of rain. The washout rate decreases with pH. For the range of pH (4 - 5) usually encountered the scavenging rate denoted by j is of the order of 10^{-5} s^{-1} (Garland, 1978). Johnson et al. (1978) use a value of $6 \times 10^{-5} \text{ s}^{-1}$ ($R = 1 \text{ mm/hr}$) in their modeling study while Fisher (1978) is forced to use 10^{-4} s^{-1} to explain the measured values of wet deposition. These relatively high values for j are a consequence of the additional "washout" associated with incloud conversion of SO_2 to SO_4 . Thus using an increased washout for SO_2 is the most convenient way to account for incloud oxidation. Increasing the conversion rate during precipitation (McNaughton and Scott, 1980) has the unrealistic feature of enhancing the sulfate concentration in the boundary layer.

Maul (1978) has inferred the value of the SO_2 washout coefficient from a time series of ambient SO_2 concentrations. He found that j could be described by the equation

$$j = \alpha R \quad (13)$$

where $\alpha \approx 3 \times 10^{-5}$. The linear dependence of j on R as well as the magnitude of α suggests that the 'apparent' SO_2 washout could be dominated by incloud oxidation of SO_2 . This idea appears to be supported by the work of Eliassen and Saltbones (1975) in which sulfur concentration in rain is related to SO_2 rather than SO_4 concentration. The effective j used in their study is $\approx 4.0 \times 10^{-5}$. On the basis of these cited values for j we used $3 \times 10^{-5} \text{ s}^{-1}$ in this model.

The precipitation scavenging of sulfate is represented by a linear removal rate \bar{j} . This assumption used by several authors (Fisher, 1978; Johnson et al., 1978) is clearly unrealistic for modeling precipitation events. However, it is probably less critical for long-term estimates of wet deposition. In this study $\bar{j} = 10^{-4} \text{ s}^{-1}$ is used on the basis of Garland's review paper (1978).

Measurements indicate that the dry deposition velocity v_d of SO_2 is of the order of 1 cm s^{-1} during daytime. Sulfate is primarily in the form of aerosol whose median diameter is below $1 \mu\text{m}$ (Garland, 1978). For this particle size range the deposition velocity is around 0.1 cm s^{-1} .

There is little guidance on the magnitude of the parameters τ_d and τ_w . As they are Lagrangian variables defined with respect to trajectories of air parcels they cannot be derived from routinely available Eulerian (fixed point)

meteorological observations. Rodhe and Grandell (1972) have estimated these parameters assuming a ratio between fixed point and Lagrangian measurements. Slinn et al. (1979) have made more reliable estimates based on actual trajectories originating from Kansas city. The averages of the January and July 1975 values are $\tau_d = 46$ hours and $\tau_w = 7$ hours which are comparable to those suggested by Rodhe and Grandell (1972). Our studies showed that model results were relatively insensitive to τ_d and τ_w , a conclusion which is in agreement with that found by Smith (1980).

Table 1 presents the model parameters used in our simulations. The values of f_d and f_w are similar to those used by Fisher (1978). f is assumed to be equal to 0.5 for the top 55 sources and zero for the rest.

MODEL TESTING

The model described in the previous sections has been used to compute sulfur in rain falling over the grid system shown in Fig. 2. The long-term sulfur deposition has been computed from

$$D_w = \left[\frac{1}{2} \bar{c}_{SO_2} + \frac{1}{3} \bar{c}_{SO_4} \right] h \quad (14)$$

Figure 3 shows contours of D_w obtained from the model. The emission inventory used corresponds to the year 1977. The figure also shows the locations of monitors set up by Canada and the United States to sample precipitation chemistry. The description of the network and the corresponding annual deposition values are given in the paper by Galloway and Whelpdale (1980).

Table 2 presents the comparison between the model predictions of sulfur wet deposition and the observations. Based on values suggested by Fisher (1978) a background deposition of $0.2 \text{ gm}^{-2}\text{a}^{-1}$ is used. It is seen from the table that model predictions of wet deposition in the CANSAP (Whelpdale and Berry, 1978) network are generally lower than the observed values. However, the model explains 76% of the measured variance in the deposition. Rejecting the value at receptor 11 as an outlier increases the r^2 to 0.84. According to Whelpdale (personal communication) the measurement technique used in the CANSAP network might have led to an overestimation of the observations by about 30%. This should explain the predictions being lower than the measured values. It is interesting to find that regressing predictions against observations reduced by 30% results in $a = 0.17 \text{ gm}^{-2}\text{a}^{-1}$ and $b = 1.04$ (regression coefficients).

The ratio of observations to predictions for the American data is distributed fairly evenly around the ideal value of unity. However, the r^2 is insignificant at 0.09. Removing the outliers at receptors 24, 25, 26 results in a marked increase of the r^2 to 0.47. It is believed that the discrepancy between model estimates and measurements is related to the fact that the American data have been drawn from a number of sources which are not likely to be consistent in quality (Galloway and Whelpdale, 1980).

Note that model testing is anything but straightforward. This is because the correspondence between model predictions and observations is very difficult to establish. The model estimate is designed to correspond to the mean of the concentration distribution to which the measured value is assumed to belong. Therefore, model predictions are expected to deviate from observations. At the present time there is little information on this expected deviation and a certain

degree of subjectivity in evaluating model performance is inevitable. For a discussion of this problem the reader is referred to Venkatram (1979).

The classification of "outliers" in the data is not based on an objective criterion. But then only 4 out of 26 points have been rejected. It is useful to point out that 77% of the observations are within a factor of two of the predictions. Based on "experience" with air pollution modeling it is believed that model estimates of wet deposition of sulfur are eminently acceptable.

Model parameters used in this paper represent "standard" values quoted in literature (See Eliassen, 1980, for a review). These are not optimum values derived by "fitting" observations to model predicted depositions. This lends credibility to the evaluation of the model.

EXAMPLES OF MODEL APPLICATIONS

The model can be used to estimate dry deposition. However, since lack of data would not allow testing of model calculations, only examples of applications of wet deposition estimates are shown. Before doing so, an interesting aspect of sulfur deposition is pointed out. Figure 4 shows the contribution of SO_2 to the total wet deposition of sulfur. It is seen that wet deposition of sulfur is dominated by the apparent washout of SO_2 . This is clearly at variance with measurements (Dana, 1980) which indicate that SO_2 contributes no more than 40% to the sulfur in rain. However, the result tends to support the theory that inclusion of oxidation of SO_2 to SO_4 is very important. As mentioned earlier the simplest method of including this process in a model is to use a high "apparent" SO_2 washout rate. It is interesting to note that other modelers (Fisher, 1978; Johnson et al., 1978) have used SO_2 wet removal rates which are comparable to

that used here.

Figures 5 and 6 show the relative contributions of the U. S. and Canada to the wet deposition of sulfur. This type of information is useful for abatement plans in relation to the acid rain problem. It is seen that south of latitude 45° more than 50% of the sulfur deposited in rain can be attributed to U. S. sources. Canadian sources in Sudbury and Noranda are major contributors primarily in regions in their vicinity. Note that background deposition of $0.2 \text{ gm}^{-2}\text{a}^{-1}$ is dominant in Northern Canada.

CONCLUSIONS

Simple statistical model can provide acceptable estimates of sulfur deposition. This supports the conclusions of the studies by Fisher (1978) and Fay and Rosenzweig (1980). It is clear that the type of results which can be obtained from statistical models are suitable for formulating abatement strategies for the acid rain problem.

This study indicates that SO_2 could be a major contributor to the wet deposition of sulfur. This supports recent indirect evidence of rapid incloud oxidation of SO_2 to SO_4 . If this is indeed physically correct modeling can be simplified by concentrating on SO_2 .

Some of the assumptions used in the model may be questionable. For example, the statistics of dispersion are not based on the analysis of trajectories. This analysis is in progress.

The constants in equations (4a) and (4b) are given by:

$$\alpha_{1,2} = -\frac{(\bar{\epsilon}_d + \bar{\epsilon}_w)}{2} \left[1 \pm \left\{ 1 - \frac{4(\bar{\epsilon}_d \bar{\epsilon}_w - g_d g_w)}{(\bar{\epsilon}_d + \bar{\epsilon}_w)^2} \right\}^{\frac{1}{2}} \right] \quad (A.1)$$

where

$$\bar{\epsilon}_d = k_d + \lambda_d + 1/\tau_d ; \bar{\epsilon}_w = k_w + \lambda_w + 1/\tau_w \quad (A.2)$$

$$g_d = 1/\tau_w ; g_w = 1/\tau_d \quad (A.3)$$

$$A_{d1} = \frac{p_d(\alpha_2 + \bar{\epsilon}_d) - p_w g_d}{(\alpha_2 - \alpha_1)} ; A_{w2} = \frac{p_w g_d - p_d(\alpha_1 + \bar{\epsilon}_d)}{(\alpha_2 - \bar{\epsilon}_1)} \quad (A.4)$$

$$A_{w1} = A_{d1} \frac{(\alpha_1 - \bar{\epsilon}_d)}{g_d} ; A_{w2} = A_{d2} \frac{(\alpha_2 + \bar{\epsilon}_d)}{g_d} \quad (A.5)$$

$$p_d = f_d^0 SO_2 ; p_w = f_w^0 SO_2 \quad (A.6)$$

$$\gamma_{1,2} = -\frac{(\bar{\epsilon}_d + \bar{\epsilon}_w)}{2} \left[1 \pm \left\{ 1 - \frac{4(\bar{\epsilon}_d \bar{\epsilon}_w - \bar{g}_d \bar{g}_w)}{(\bar{\epsilon}_d + \bar{\epsilon}_w)^2} \right\}^{\frac{1}{2}} \right] \quad (A.7)$$

$$\bar{\epsilon}_d = \bar{\lambda}_d + 1/\tau_d ; \bar{g}_d = 1/\tau_w \quad (A.8)$$

$$\bar{\epsilon}_w = \bar{\lambda}_w + 1/\tau_w ; \bar{g}_w = 1/\tau_d \quad (A.9)$$

$$\beta_{di} = \frac{\bar{k}_d A_{di}(\alpha_i + \bar{\epsilon}_w) + \bar{g}_d A_{wi} k_w}{\epsilon_i} \quad (A.10)$$

$$\beta_{wi} = \frac{\bar{k}_w A_{wi}(\alpha_i + \bar{\epsilon}_d) + \bar{g}_w A_{di} k_d}{\epsilon_i} \quad (A.11)$$

$$\epsilon_i = (\alpha_i + \bar{\epsilon}_d)(\alpha_i + \bar{\epsilon}_w) - \bar{g}_w \bar{g}_d \quad (A.12)$$

and

$$\beta_{d1} = \frac{v_d(\gamma_2 + \bar{\epsilon}_d) - v_w \bar{g}_d}{(\gamma_2 - \gamma_1)} ; \beta_{d2} = \frac{v_d \bar{g}_d - v_w(\gamma_1 + \bar{\epsilon}_d)}{(\gamma_2 - \gamma_1)} \quad (A.13)$$

$$\beta_{w1} = \frac{\beta_{d1}(\gamma_1 + \bar{\epsilon}_d)}{\bar{g}_d} ; \beta_{w2} = \frac{\beta_{d2}(\gamma_2 + \bar{\epsilon}_d)}{\bar{g}_d} \quad (A.14)$$

where

$$v_d = - \sum_{i=1}^2 \beta_{di} + f_d^0 SO_4 \quad ; \quad v_w = - \sum_{i=1}^2 \beta_{wi} + f_w^0 SO_4 \quad (A.15)$$

$$\bar{k}_d = \frac{3}{2} k_d \quad ; \quad \bar{k}_w = \frac{3}{2} k_w \quad (A.16)$$

Table 1

Model parameters used in "base" case simulations

1. Scavenging parameters

SO ₂ dry deposition velocity (v_d)	=	$0.5 \times 10^{-2} \text{ms}^{-1}$
SO ₄ dry deposition velocity (\bar{v}_d)	=	$0.05 \times 10^{-2} \text{ms}^{-1}$
Dry period SO ₂ to SO ₄ conversion rate (k_d)	=	1%/hr
Wet period SO ₂ to SO ₄ conversion rate (k_w)	=	1%/hr
SO ₂ wet removal rate (j)	=	$3 \times 10^{-5} \text{s}^{-1}$
SO ₄ wet removal rate (\bar{j})	=	$1 \times 10^{-4} \text{s}^{-1}$

2. Meteorological parameters

Average mixed layer height (z_i)	=	1000 m
Advecting wind speed (u)	=	10 ms ⁻¹
Dispersion velocities (σ_u, σ_v)	=	10 ms ⁻¹ , 6 ms ⁻¹
Lagrangian dry period duration (τ_d)	=	46 hr
Lagrangian wet period duration (τ_w)	=	7 hr
Fractional dry period at source (f_d)	=	0.9
Fractional wet period at source (f_w)	=	0.1
Emission ratio at source $Q_{\text{SO}_2}/Q_{\text{SO}_4}$	=	0.98/0.02

Table 2

Station No.	Receptor Name	Wet sulfur deposition		
		OBS ($\text{gm}^{-2}\text{a}^{-1}$)	PRED	OBS/PRED
1	Kingston, Ont.	1.26	0.93	1.35
2	Moosonee, Ont.	0.58	0.33	1.76
3	Mount Forest, Ont.	2.32	0.96	2.42
4	Peterborough, Ont.	1.81	0.94	1.93
5	Pickel Lake, Ont.	0.39	0.28	1.39
6	Simcoe, Ont.	2.34	1.49	1.57
7	Wawa, Ont.	0.91	0.52	1.75
8	Windsor, Ont.	2.98	2.00	1.49
9	Chibougamau, Que.	1.06	0.42	2.52
10	Maniwaki, Que.	0.71	0.75	0.95
11	Montreal, Que.	2.35	0.88	2.67
12	Merrimach Cnty, N.Y.	0.91	0.93	0.98
13	Albany Cnty, N.Y.	1.20	1.21	0.99
14	Allegany Cnty, N.Y.	2.20	1.58	1.39
15	Dutchess Cnty, N.Y.	1.20	1.48	0.81
16	Essex Cnty, N.Y.	0.84	0.84	1.00
17	Oneida Cnty, N.Y.	1.70	1.08	1.57
18	Onondaga Cnty, N.Y.	0.79	1.19	0.66
19	Ontario Cnty, N.Y.	1.20	1.34	0.90
20	St. Law. Cnty, N.Y.	1.00	0.89	1.12
21	Oak Ridge, Tenn.	1.30	1.04	1.25
22	Charlottesville, Vir.	0.91	1.31	0.69
23	Tucker Cnty, W.V.	2.00	1.94	1.03
24	Washington, D.C.	1.00	1.83	0.55
25	Lewistown, Penn.	0.98	2.21	0.44
26	Paducah, Kentucky	0.57	1.29	0.44

LINEAR ANALYSIS: OBSERVED DEPOSITION = $a + b * \text{PREDICTED DEPOSITION}$

Receptor Location	r^2	$a(\text{g}/\text{m}^2/\text{yr})$	b	Receptor Excluded
Canada	0.76	0.24	1.49	
Canada	0.84	0.16	1.48	11
U.S.	0.09	0.73	0.34	
U.S.	0.47	0.05	0.98	24, 25, 26
All PT	0.19	0.67	0.58	
All PT	0.51	0.24	1.04	11, 24, 25, 26
All PT Can Obs Reduced 30%	0.70	0.12	0.97	11, 24, 25, 26

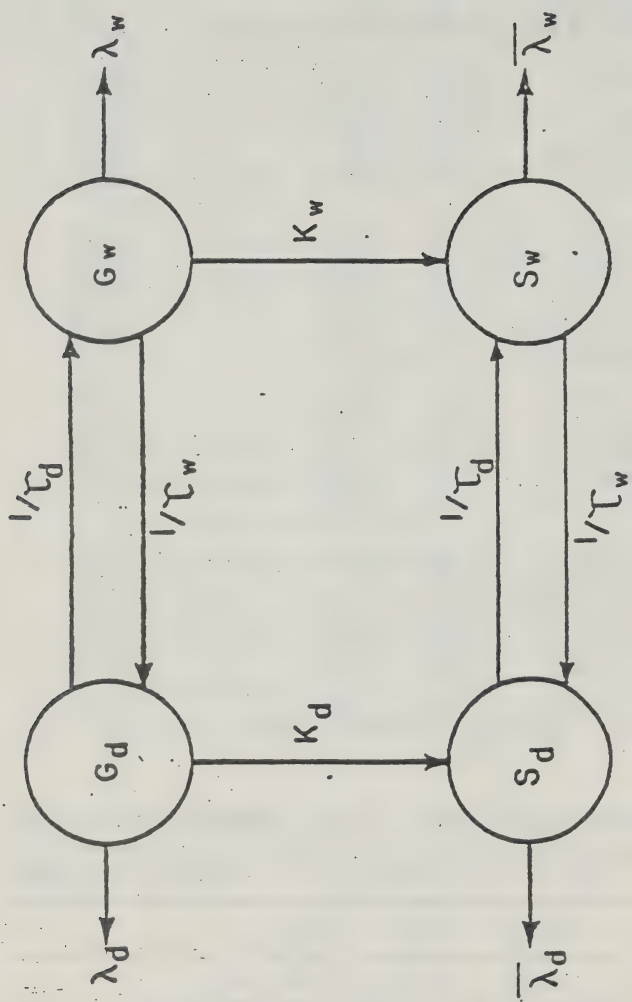
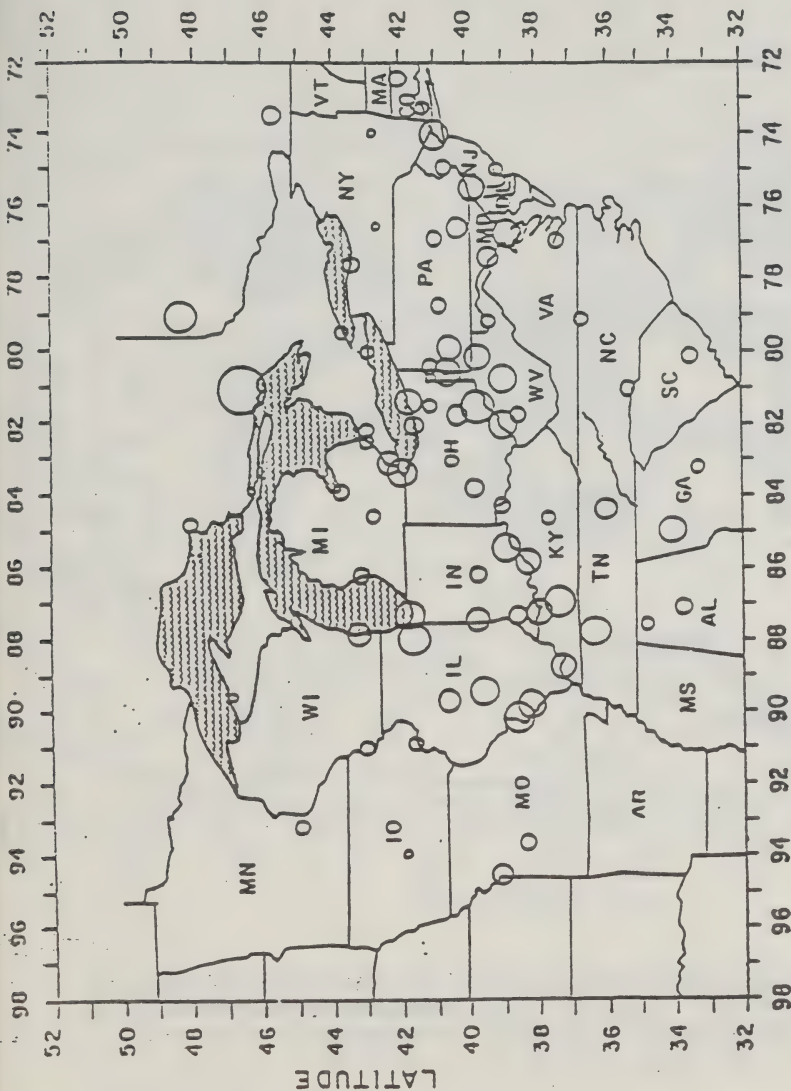
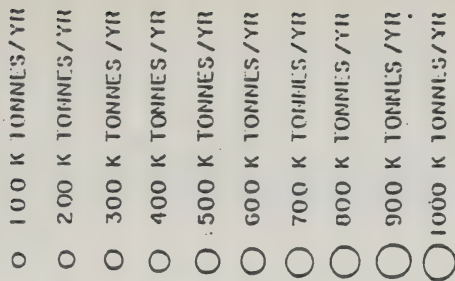


FIGURE 1: Schematic diagram of the scavenging model.

LEGEND



LONGITUDE

SOURCES OFF THE MAP

EMISS	SOURCE NAME	LAT	LONG	EMISS	SOURCE NAME	LAT	LONG
○	PORTLAND - AUGUSTA	43.4	71.0	○	FLIN FLON MAN	54.9	101.0
○	BOSTON - WORCESTER	40.3	71.3	○	MONCTON N.B.	45.5	66.0
○	NEWPORT-FALL RIVER	41.7	71.1	○	NOVA SCOTIA	45.0	62.0
○	THOMPSON, MAN.	55.4	97.5	○	GASPE DAY QUEBEC	40.0	65.3

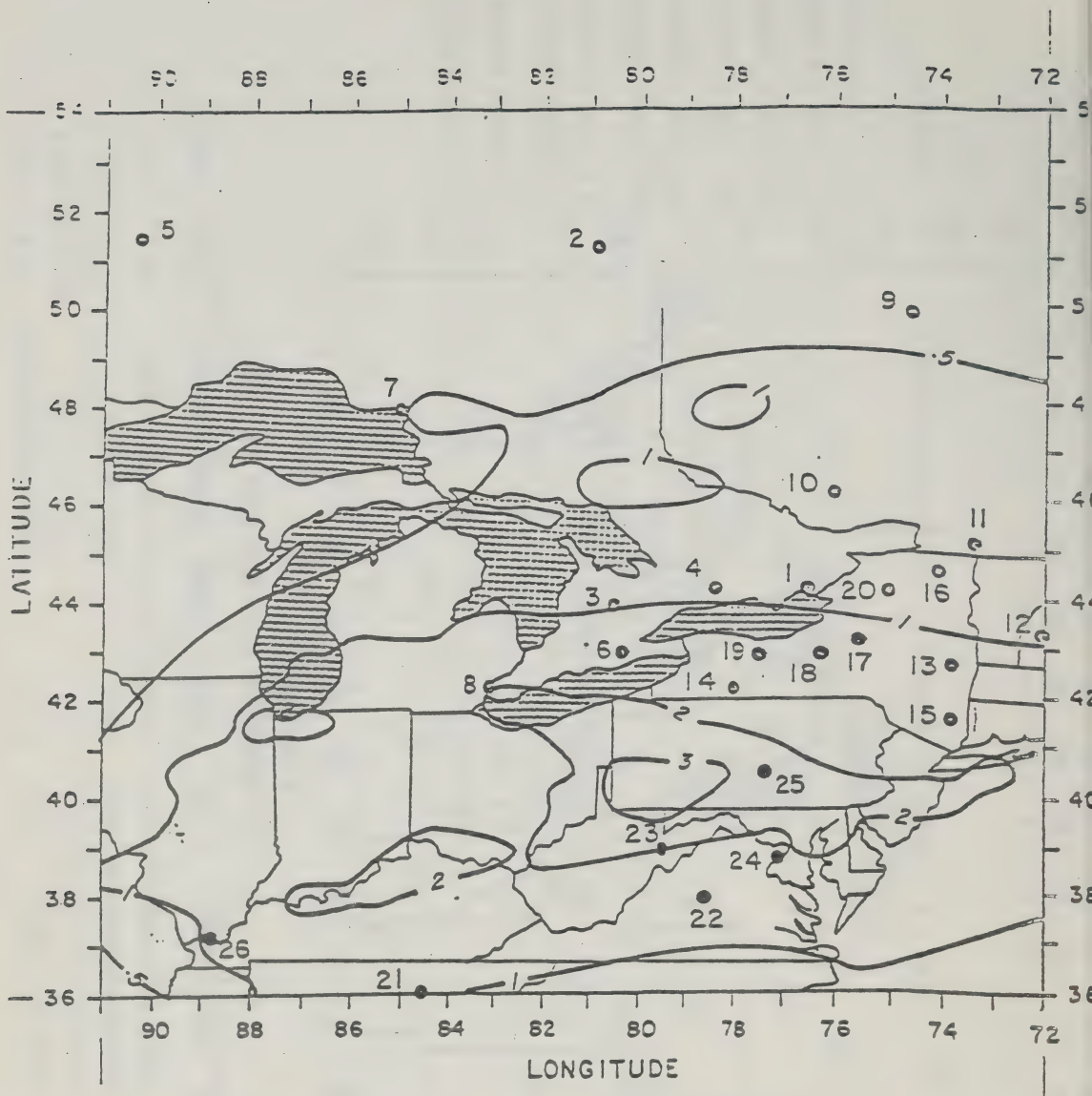


FIGURE 3: Model predictions of annual wet deposition of sulfur in $\text{gm/m}^2/\text{a}$. Stars in figure correspond to monitors in the CANSAF and U.S. networks. Numbers next to stars are station codes referred to in Table 2.

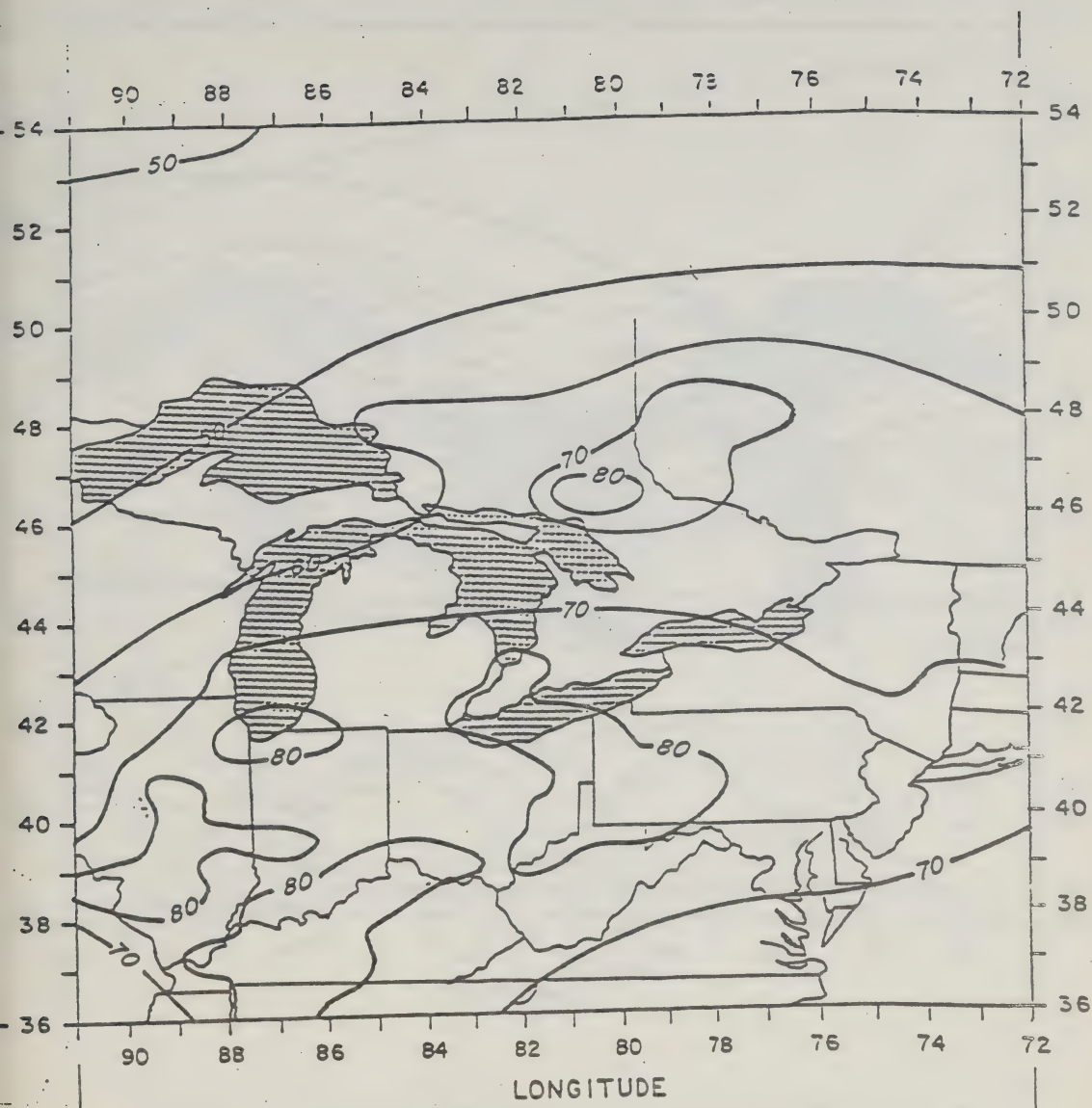


FIGURE 4: Relative contribution of SO_2 to the total wet deposition of sulfur.

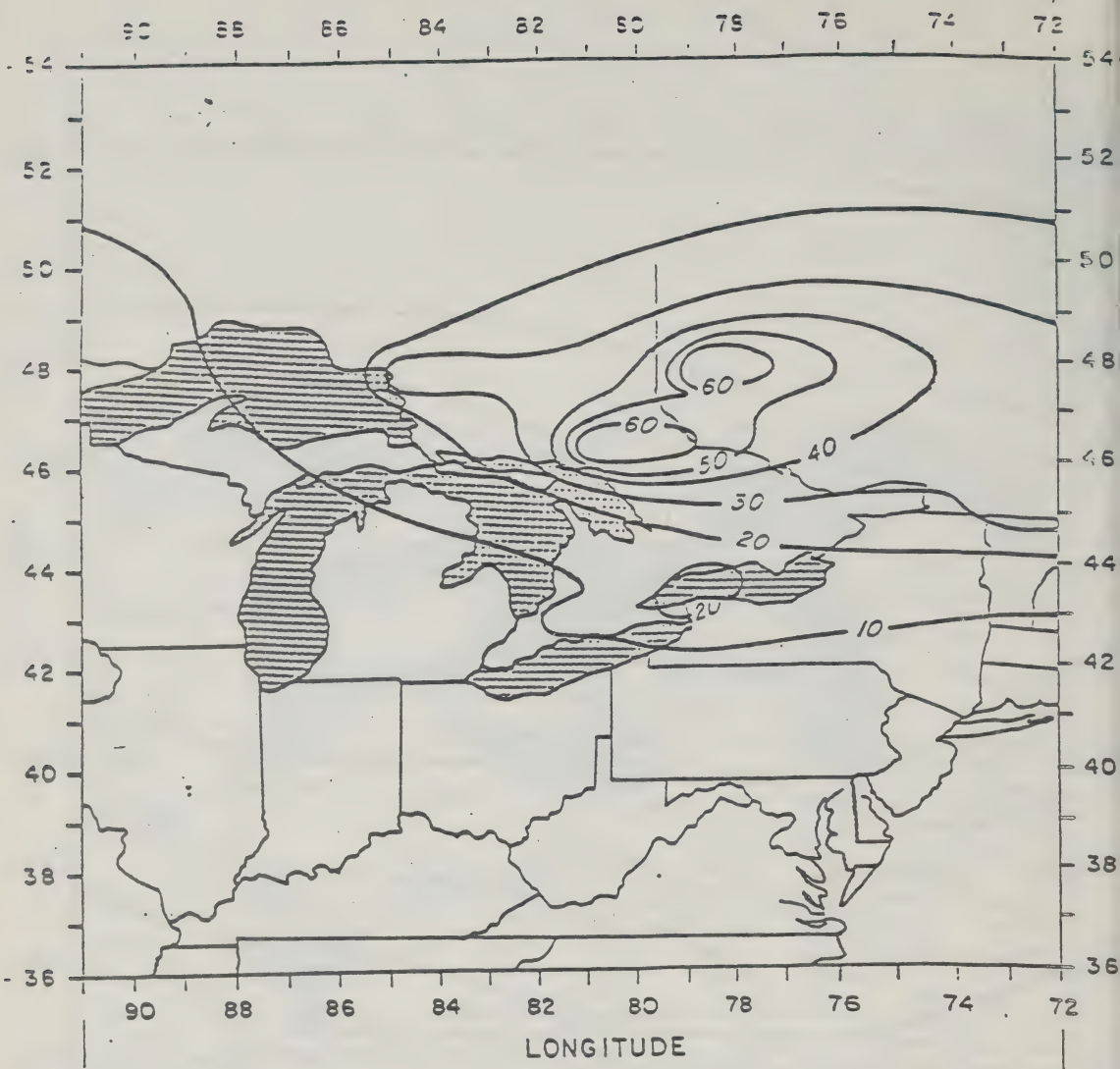


FIGURE 5: Percentage contribution of Canadian SO_x sources to the wet deposition of sulfur.

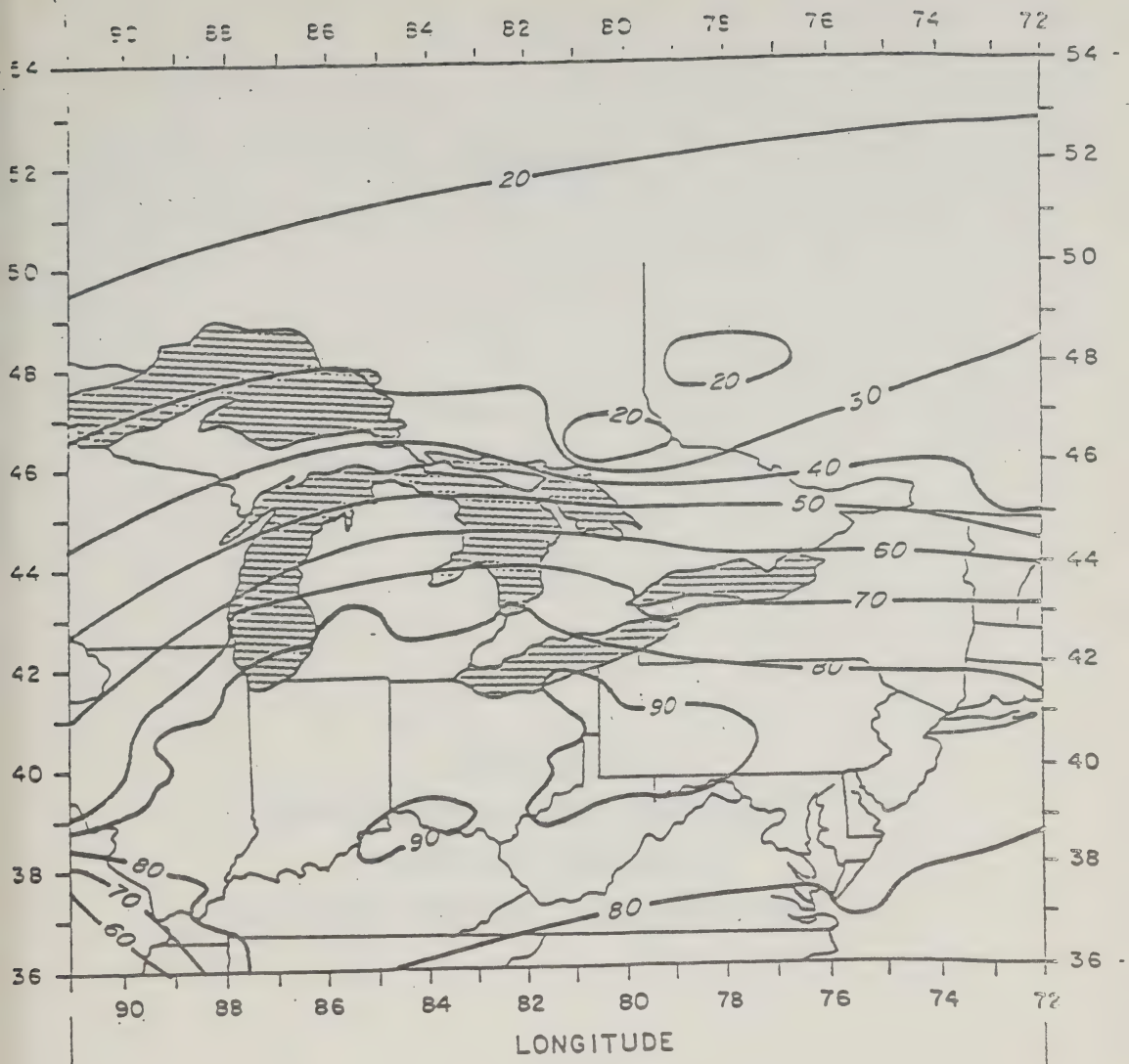


FIGURE 6: Percentage contribution of U.S. SO_x sources to the wet deposition of sulfur.

APPENDIX 8

Excerpts from
Ontario Ministry of the Environment
Report #ARB-038-81
Entitled

"MODEL PROFILE
ONTARIO MINISTRY OF THE ENVIRONMENT
STATISTICAL MODEL OF THE
LONG RANGE TRANSPORT OF AIR POLLUTION"

SENSITIVITY STUDY

The model sensitivity to uncertainty in the value of the input parameters was tested by independently varying each parameter within the range of values cited in the recent literature. (See the previous section for specific parameter references). All model parameters are tested separately except f_d and f_w ($f_w = 1.0 - f_d$). The variation ranges of the model parameters are summarized in Table 1 along with "base" case values retained by all parameters except the one being studied.

For this test an idealized source-receptor geometry was chosen to enable the testing a model sensitivity to the input parameters as a function of the source-receptor orientation. The geometry selected is depicted in Figure 1. Since the model formulation results in a distribution which is symmetric with respect to the mean wind only receptors in the first two quadrants were required.

The results of this model sensitivity test are shown in Figure 2. Plotted is the annual wet deposition of sulfur per unit emission on a log-log scale as a function of the parameter being studied. Figure 2 consists of eighteen pages, one page for each receptor. The pages are numbered in the same order in which the receptors are numbered in Figure 1. A log-log plot was chosen in order to display the fractional change in the calculated deposition in terms of a fractional change in the model parameter η_i , i.e.

$$\frac{dD}{d\eta_i} \cdot \left(\frac{\eta_i}{D} \right) = \frac{d \ln D}{d \ln \eta_i}$$

Figure 2 may be summarized in terms of the input parameter under consideration and the relative location of the receptor with respect to the source.

Dry conversion rate (k_d):

For receptors down wind of the source the calculated wet deposition rate is insensitive to values of k_d (.5% to 1.2%) except at large distances (~1000 km). The result is the same at cross wind receptors. Elsewhere the calculation is insensitive to the value of k_d .

Wet conversion rate (k_w):

At near source receptor sites the deposition is sensitive to values of k_w greater than 5% hr^{-1} . Below this conversion rate there is no significant sensitivity. The conversion rate must be large to show sensitivity due to the magnitude of other pathways for wet deposition (eg. wet deposition of SO_2). At large distances wet deposition is not sensitive to the wet conversion rate - again other pathways dominate.

Dry deposition velocity of SO_2 :

Wet deposition is sensitive to this parameter at all locations particularly at large distances. This is due to the loss of sulfur for wet deposition by dry deposition.

Dry deposition velocity of SO_4 :

For the range of SO_4 dry deposition velocities considered the estimate of wet deposition does not depend on this parameter (very small pathway).

Wet deposition rate of SO_2 :

Wet deposition is very sensitive to this parameter downwind and near the source. This pathway near the source can result in greater than 80% of the sulfur deposited wet to be from SO_2 . Far from the source wet deposition is less sensitive to this parameter as other pathways to wet deposition become important and suspended wet SO_2 has been depleted or converted.

Wet deposition rate of SO_4 :

This pathway for wet sulfur deposition is marginally sensitive to the value of deposition rate as the total amount of wet SO_4 avail-

able for scavenging is controlled by other model parameters (eg. k_w , τ_w).

Mixed layer height:

Due to the assumption of vertical homogeneity an increased mixed layer height reduces the ground level concentration thereby reducing the loss dry deposition while the wet scavenging rate remains constant. Therefore at all locations the wet deposition rate increases are mixed height increases.

Fraction of time (Eulerian) dry (f_d) or wet (f_w):

The estimated wet deposition is sensitive to these parameters in the down wind, near source area. These locations are near enough to the source that the nature of the pollutant (wet or dry) emitted is not 'forgotten'. (i.e. travel time < time taken to loose the particles identity (τ_w or τ_d)). For these regions if we increase the fraction emitted wet then wet deposition increases proportionally.

Lagrangian duration of wet (τ_w) and dry (τ_d) periods:

The model estimate of wet deposition is sensitive to these parameters for all source-receptor orientations as the parameter control the rate of exchange between wet and dry particles.

Horizontal, along wind dispersion (σ_u):

The model estimate of wet deposition is sensitive to this parameter as it controls the probability of the emission reaching a receptor. Least sensitive are the directly downwind sites which do not rely on dispersion to transport the emission. Conversely upwind sites depend solely on dispersion and are the most dependent on this parameter.

Horizontal, cross wind dispersion (σ_v):

All receptor sites are sensitive to this parameter. As for σ_u , this parameter controls the value of the probability. Sites least affected are cross wind, near source sites. The greatest influence of this parameter is at near source sites, down wind from the source due to pollutant depletion by cross wind spread.

Mean wind speed:

All receptor sites are sensitive to this parameter. Wet deposition at a site will increase or decrease with increased wind speed depending upon whether increase wind speed will move the pollutant toward or away from the receptor more quickly.

Wind direct:

All down-wind sites are sensitive to the wind direction; however, for the range chosen (255° - 285°) directly up-wind sites do not show any sensitivity. Deposition is maximum for those sites directly down wind.

T A B L E 1

Model parameters used in "base" case simulations and parameters' variation ranges

1. Scavenging Parameters

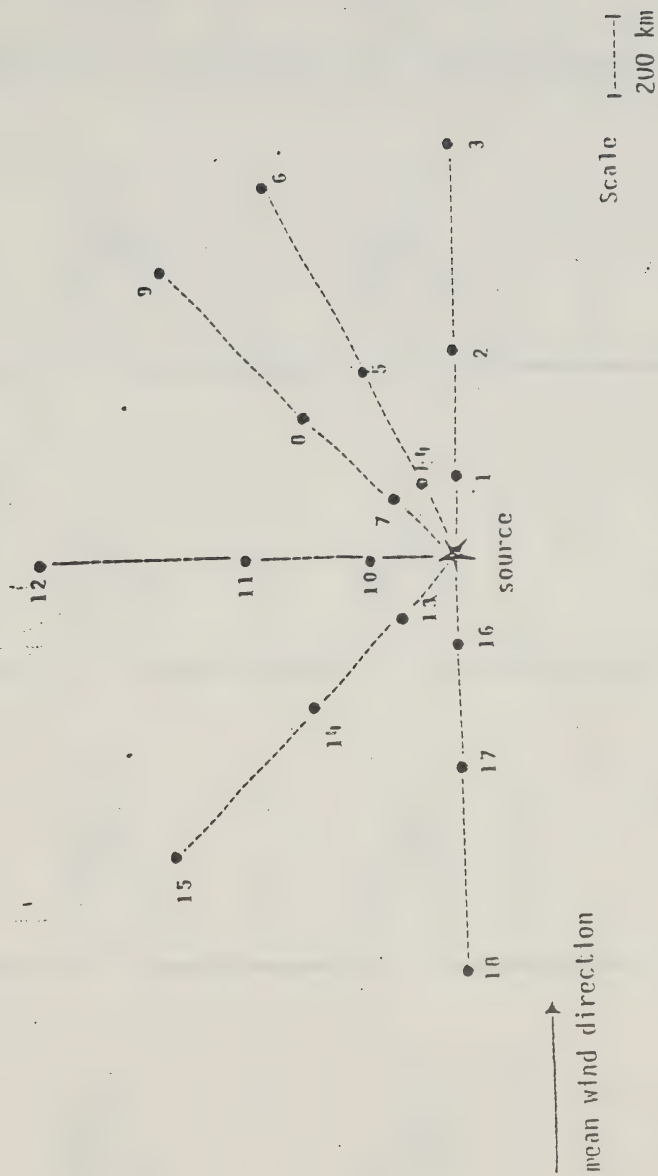
Parameter	Description	Nominal Value	Variation Range
VD	SO ₂ dry deposition velocity (V _D)	$0.5 \times 10^{-2} \text{ ms}^{-1}$	$(0.5 - 1.5) \times 10^{-2} \text{ ms}^{-1}$
VDBAR	SO ₄ dry deposition velocity (\bar{V}_D)	$0.05 \times 10^{-2} \text{ ms}^{-1}$	$(.05 - .15) \times 10^{-2} \text{ ms}^{-1}$
KD	Dry period SO ₂ to SO ₄ conversion rate (k _D)	1% hr ⁻¹	$(.6 - 1.2)\% \text{ hr}^{-1}$
KW	Wet period SO ₂ to SO ₄ conversion rate (k _w)	1% hr ⁻¹	$(1 - 10)\% \text{ hr}^{-1}$
LAMDA	SO ₂ wet removal rate (j)	$3 \times 10^{-5} \text{ s}^{-1}$	$(1 - 5) \times 10^{-5} \text{ s}^{-1}$
LAMDAB	SO ₄ wet removal rate (\bar{j})	$1 \times 10^{-4} \text{ s}^{-1}$	$(.5 - 3) \times 10^{-4} \text{ s}^{-1}$

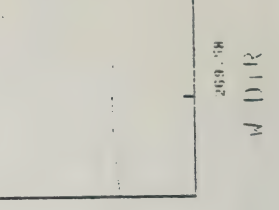
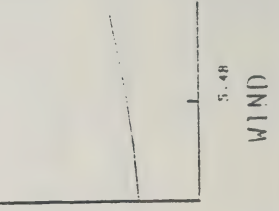
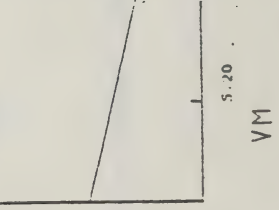
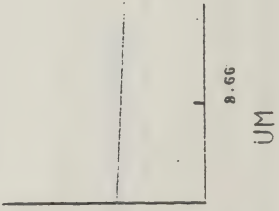
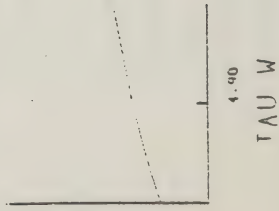
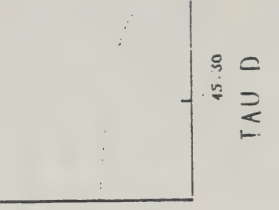
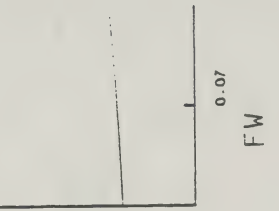
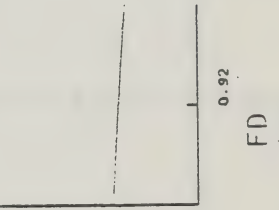
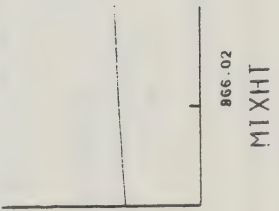
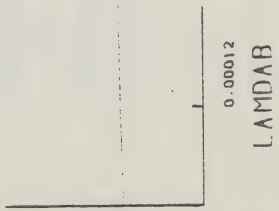
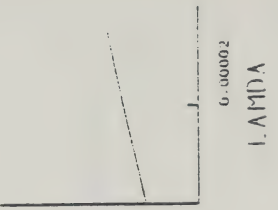
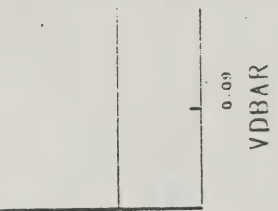
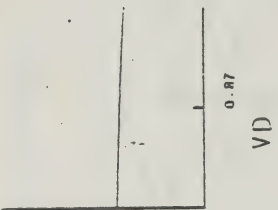
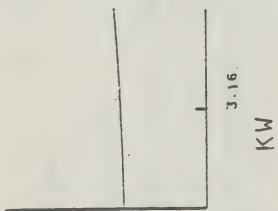
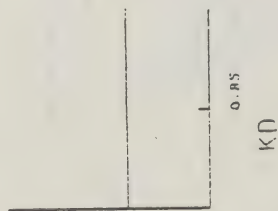
2. Meteorological Parameters

MIXHT	Average mixed layer height (z _i)	1000 m	(500 - 1500)m
WIND	Advecing wind speed (u)	10 ms ⁻¹	(2 - 15) ms ⁻¹
WDIR	Wind direction	270°	255° - 285°
(UM, VM)	Dispersion velocities (σ _u , σ _v)	10 ms ⁻¹ , 6 ms ⁻¹	(5 - 15) ms ⁻¹ , (3 - 9) ms ⁻¹
TAUD	Lagrangian dry period duration (τ _d)	46 hr	(38 - 54) hr
TAUW	Lagrangian wet period duration (τ _w)	7 hr	(2 - 12) hr
FD	Fractional dry period at source (f _d)	0.9	.88 - .96
FW	Fractional wet period at source (f _w)	0.1	.04 - .12
	Emission rate at source QSO ₂ /QSO ₄	.98/.02	unchanged

FIGURE 1

Idealized Source - Receptor Geometry used for Model Sensitivity Studies

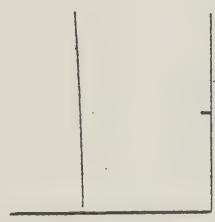






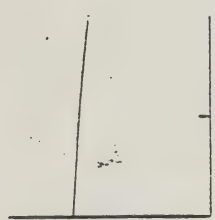
0.85

KD



3.16

KW



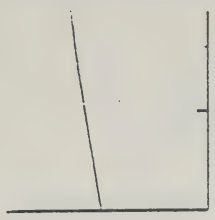
0.87

VD



0.09

VDBAR



0.00002

LAMDA



0.00012

LAMBAR



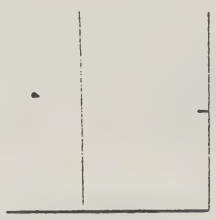
886.02

MIXHT



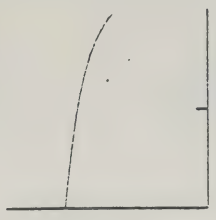
0.92

ED



0.07

EW



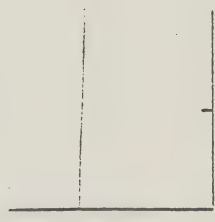
45.50

TAU D



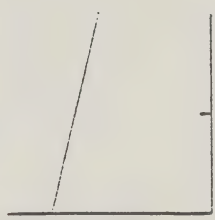
4.00

TAU W



8.66

UM



5.20

VM



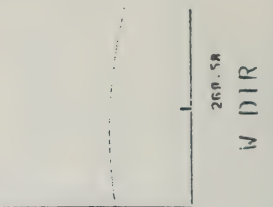
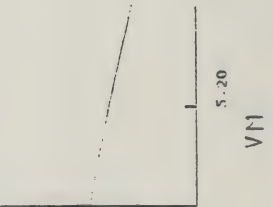
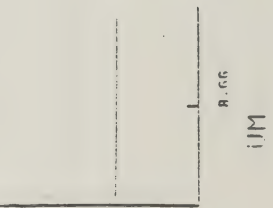
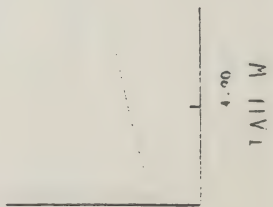
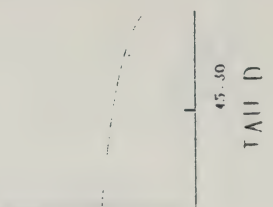
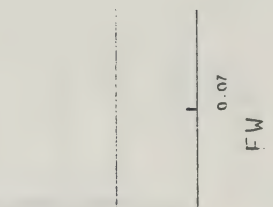
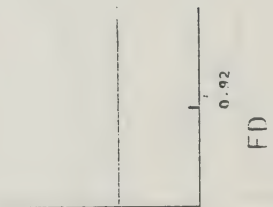
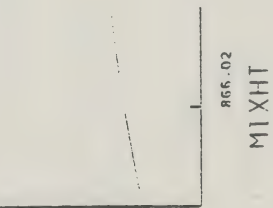
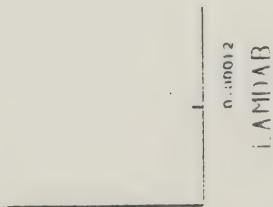
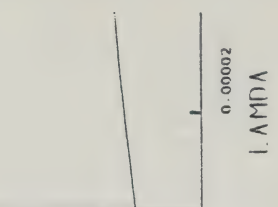
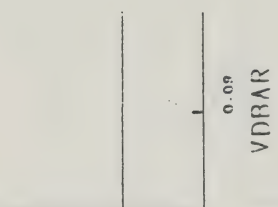
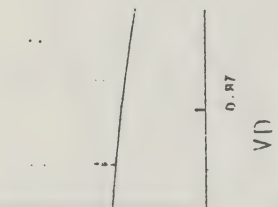
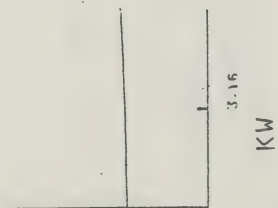
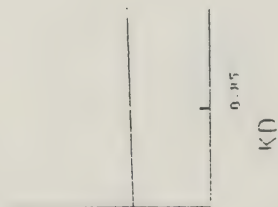
5.48

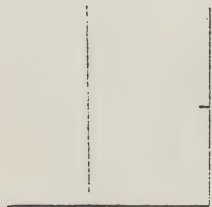
WIND



269.58

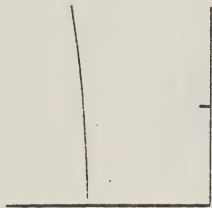
W DIR





0.85

KD



3.16

KW



0.87

VD



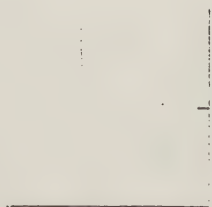
0.08

VDBAR



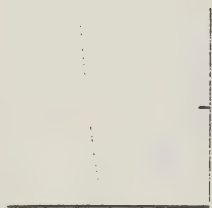
0.00002

LAMDA



0.00012

LAMDA



866.02

MIXHT



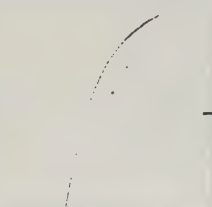
0.92

FD



0.07

FW



45.10

TAU D



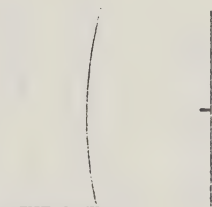
4.00

TAU W



8.66

UM



5.20

VM



5.48

WIND

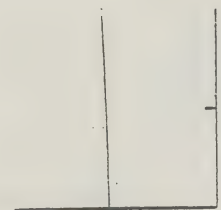


269.58

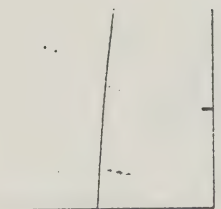
WDIR



0.85
K(D)



3.36
KW



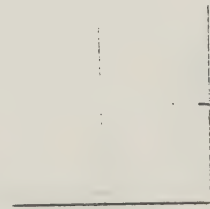
0.87
V(D)



0.09
VDRAR



0.00002
LAMDA



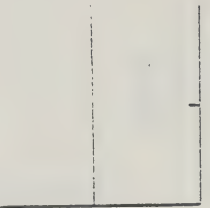
0.30012
LAMDA B



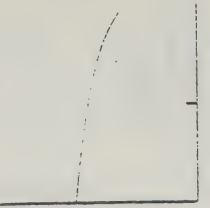
866.02
MIXHT



0.92
F(D)



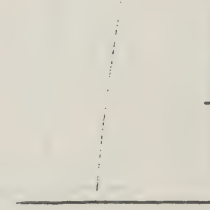
0.07
F W



45.30
TAU D



4.70
TAU W



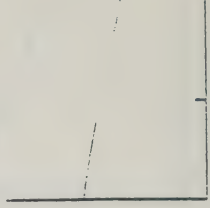
8.66
UM



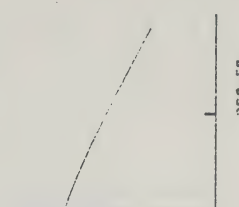
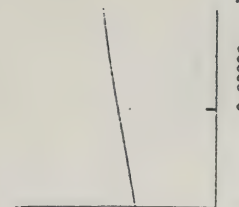
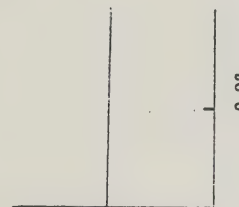
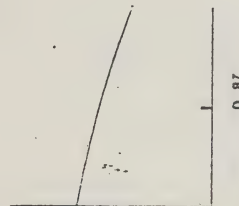
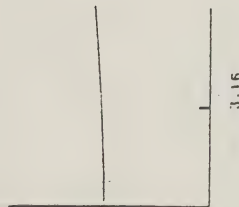
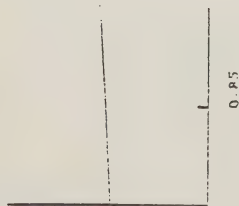
5.20
VM

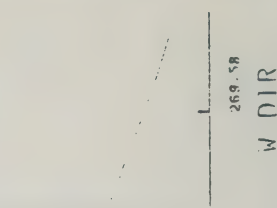
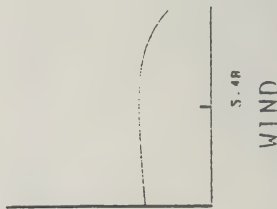
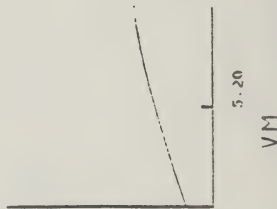
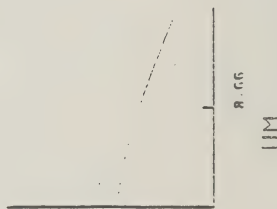
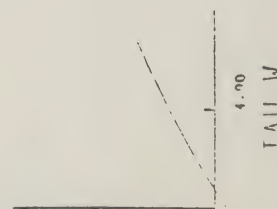
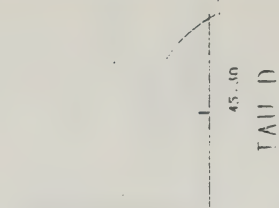
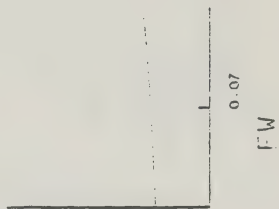
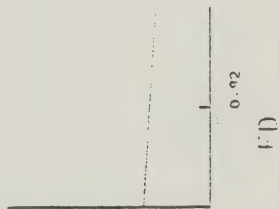
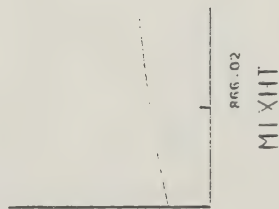
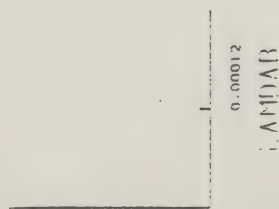
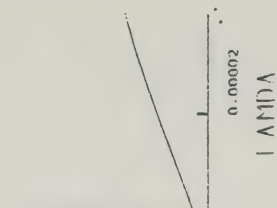
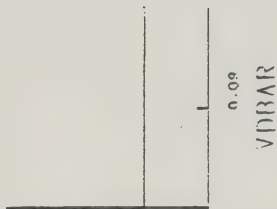
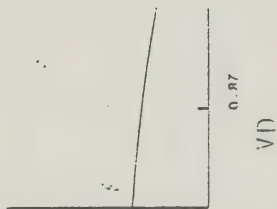
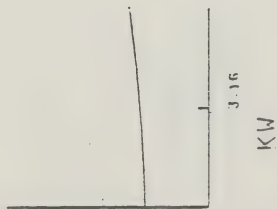
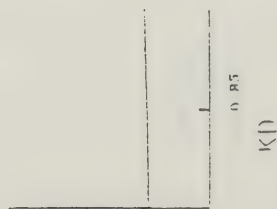


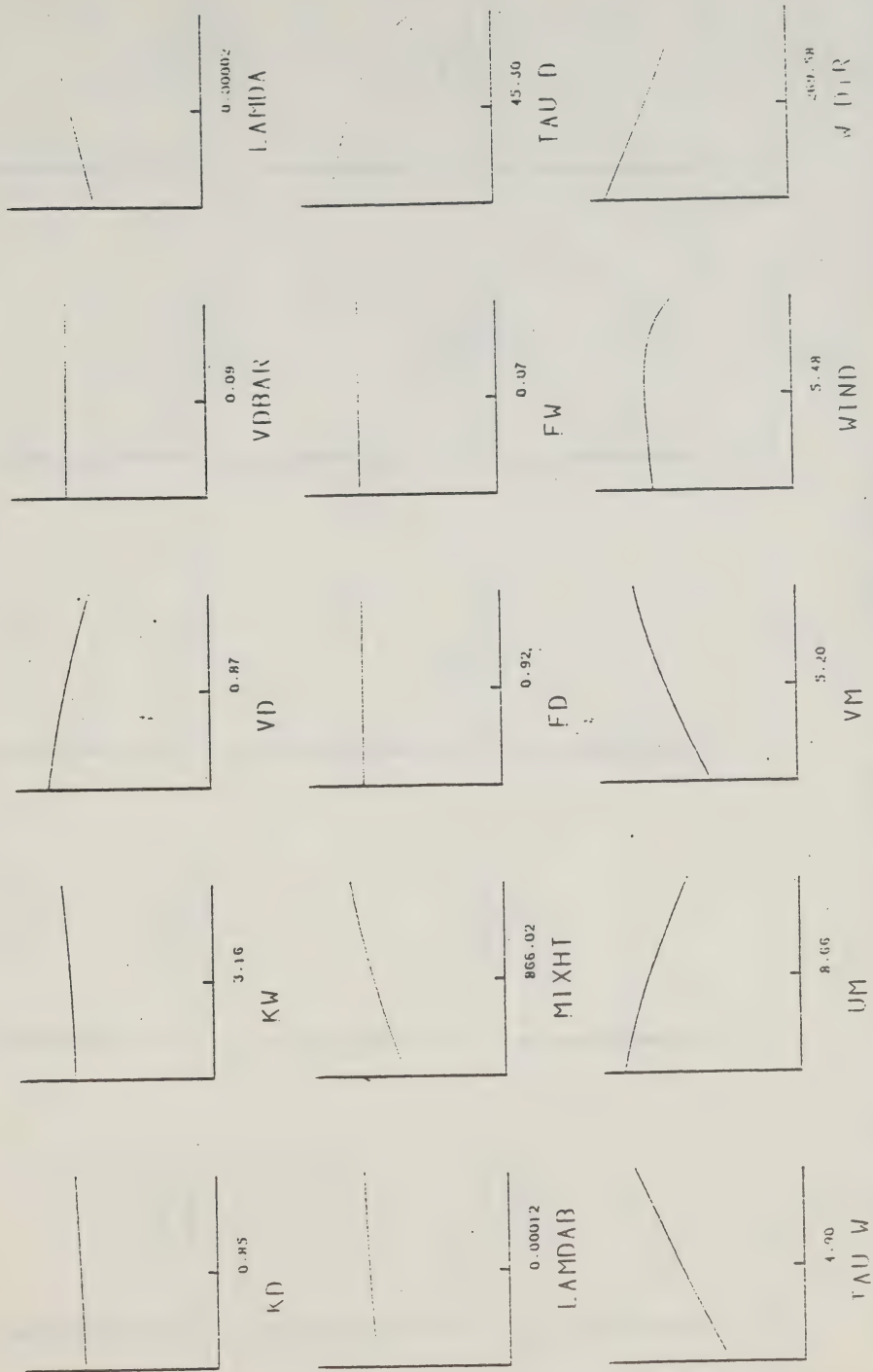
5.48
WND

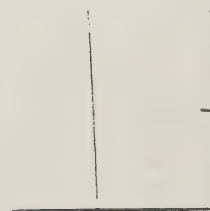


289.58
W DIR



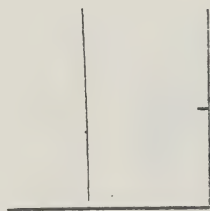






0.85

K_D



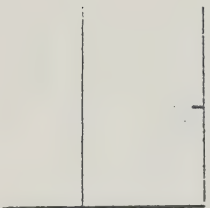
3.16

KW



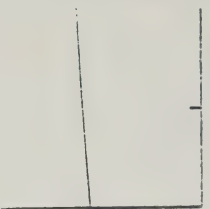
0.87

V_D



0.00

VDRAR



0.00002

LAMDA



0.00012

LAMBAR



0.02

MIXIT



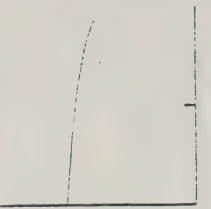
0.92

F_D



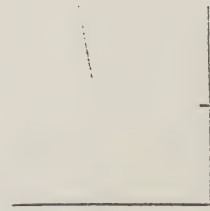
0.07

F_W



45.30

TAU D



4.00

TAU W



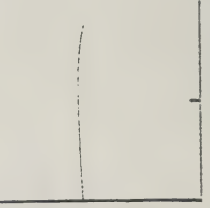
0.66

UM



5.20

VM



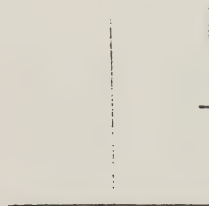
5.48

WIND

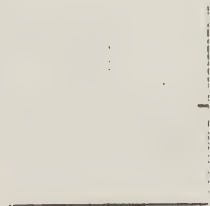


269.58

W DIR



KD
0.00012



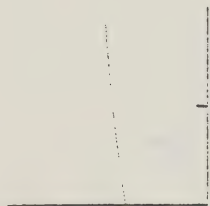
MIXHT
0.00012



TAU W
4.00



KW
3.16



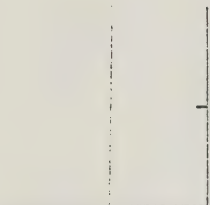
MIXHT
0.00012



UM
8.66



VD
0.87



FD
0.02



VM
5.20



VDRAR
0.09



FW
0.07



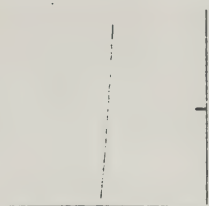
WIND
5.48



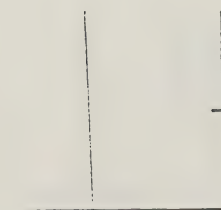
LAMDA
0.00002



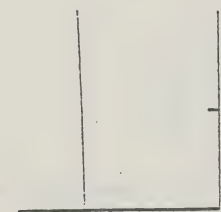
TAU D
45.10



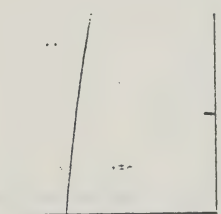
W DIR
269.58



KD
0.85



KW
3.16



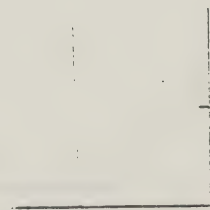
VD
0.87



VDBAR
0.09



LAMDA
0.00002



LAMBDA B
0.00012



MIXIT
866.02



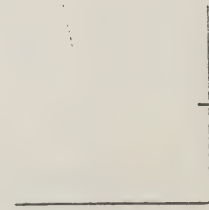
FD
0.92



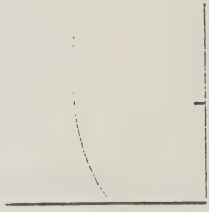
FW
0.07



TAU D
43.50



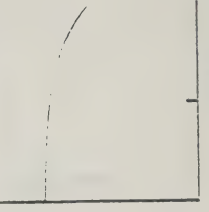
TAU W
4.00



UM
8.66



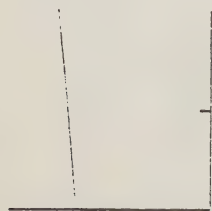
VM
5.20



WIND
5.48

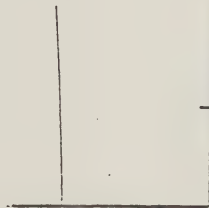


W DIR
269.58



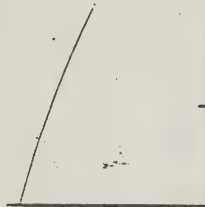
0.85

KD



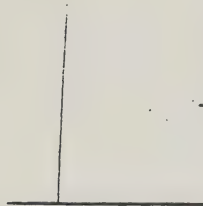
3.16

KW



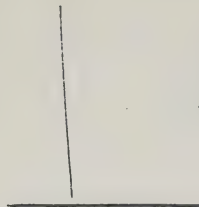
0.87

VD



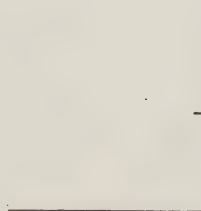
0.09

VDRAR



0.00002

LAMDA



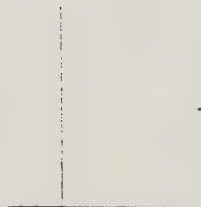
0.00012

LAMDA B



866.02

MIXHT



0.92

FD



0.07

FW



45.30

TAU D



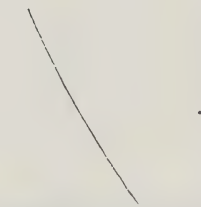
4.00

TAU W



8.66

UM



5.20

VM



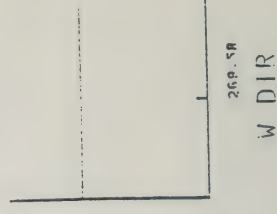
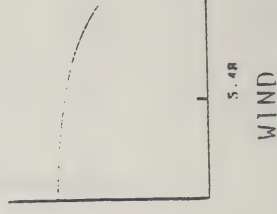
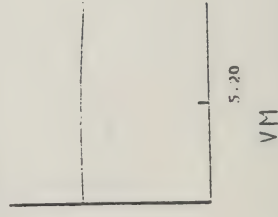
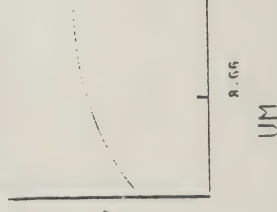
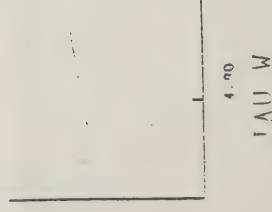
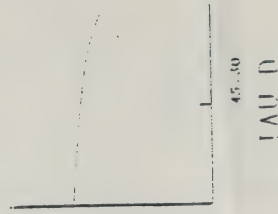
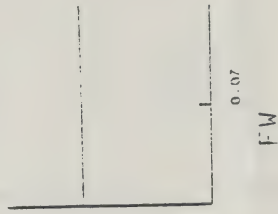
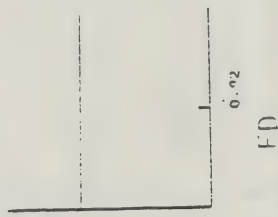
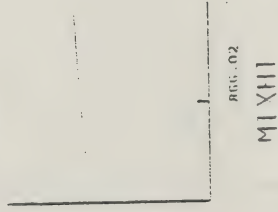
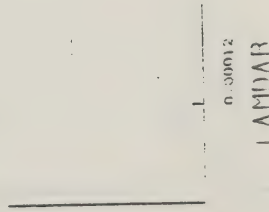
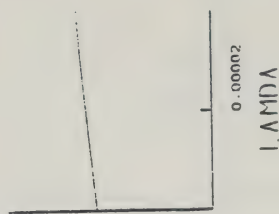
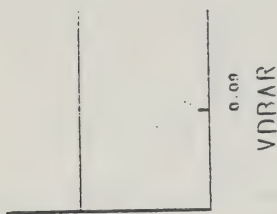
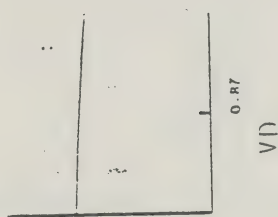
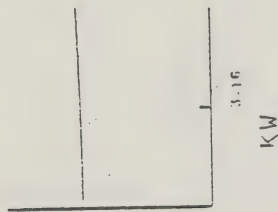
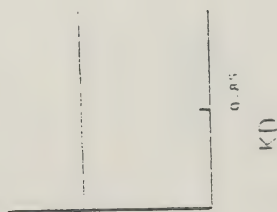
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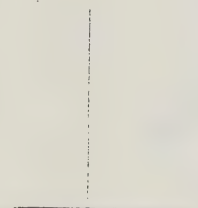
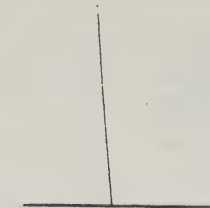
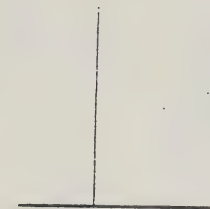
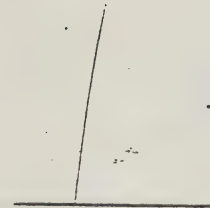
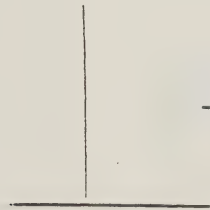
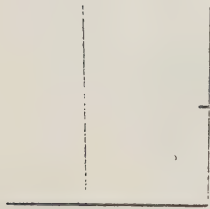
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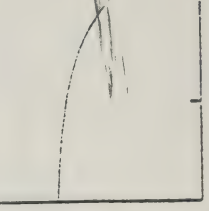
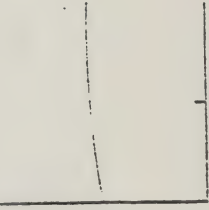
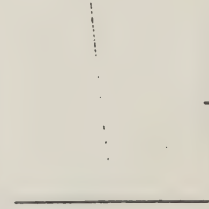
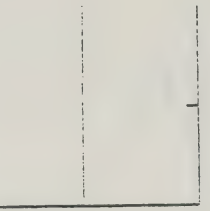
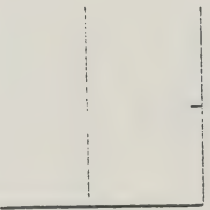
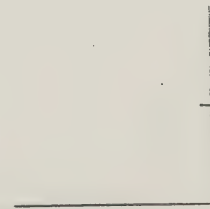
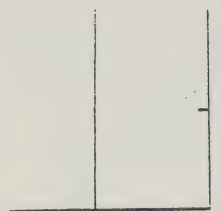
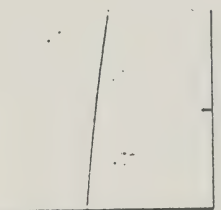
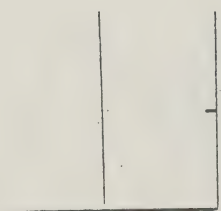
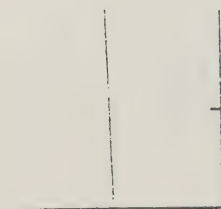


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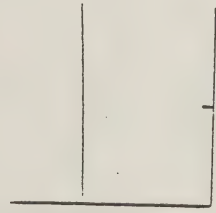






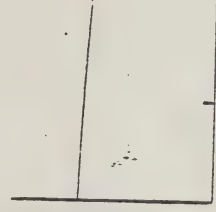
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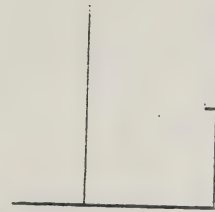
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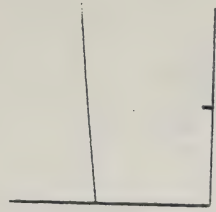
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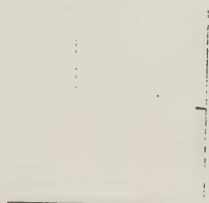
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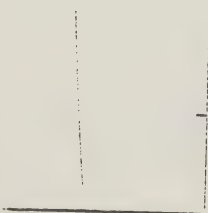
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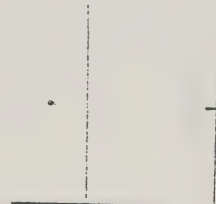
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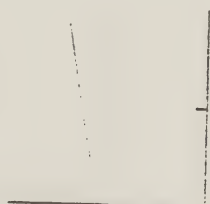
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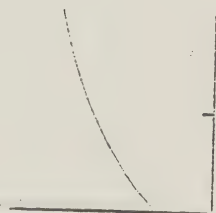
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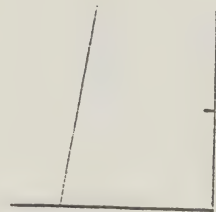
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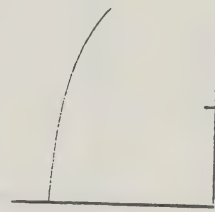
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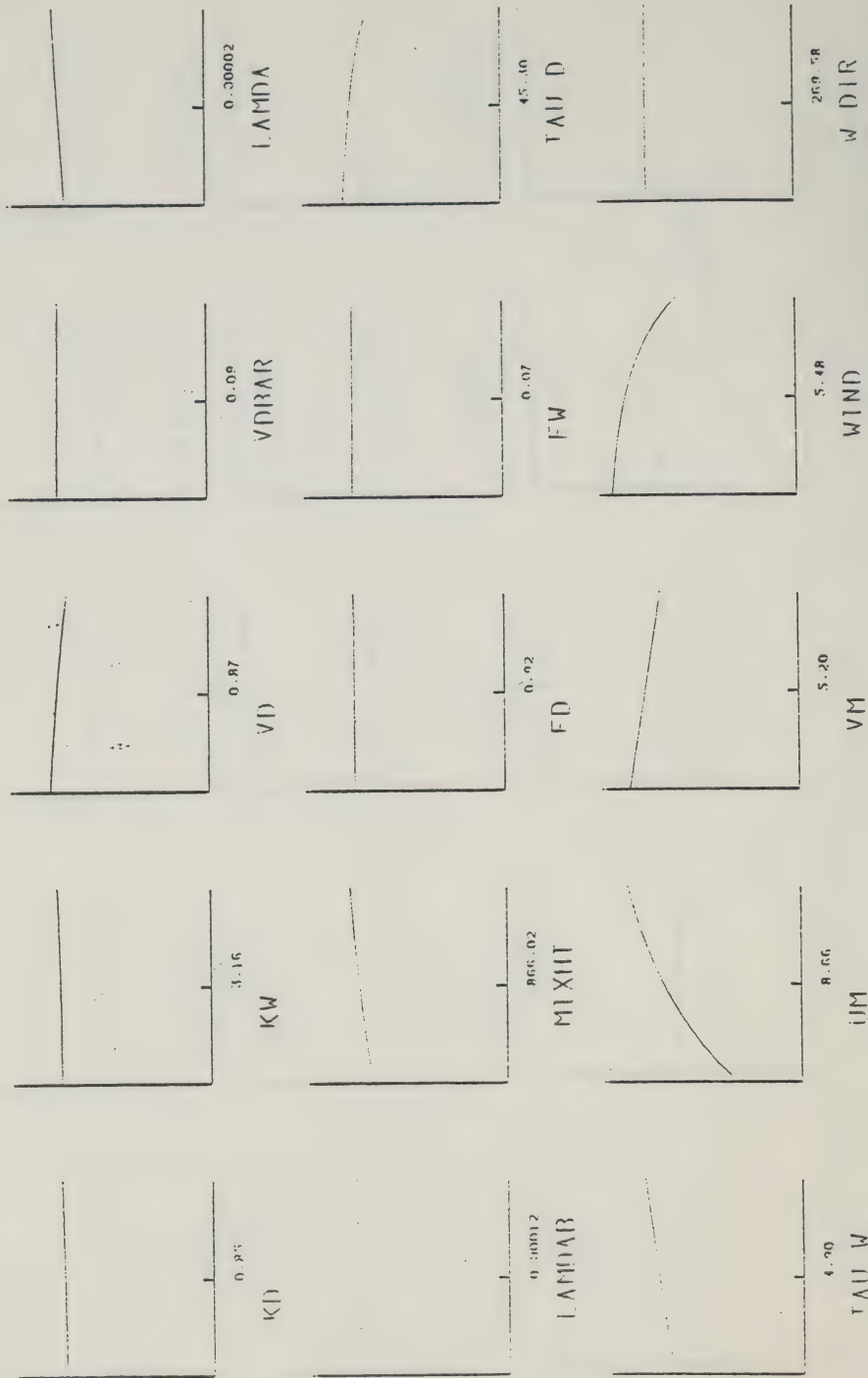
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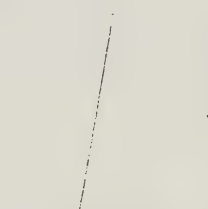
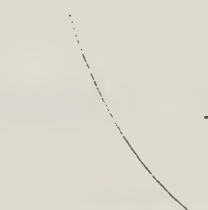
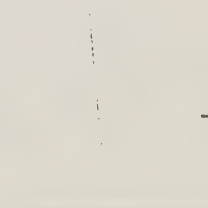
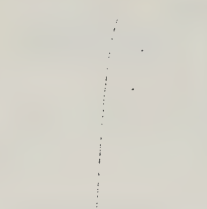
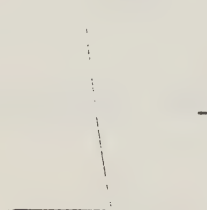
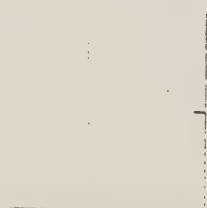
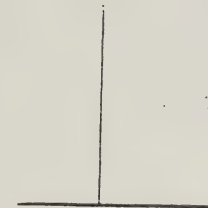
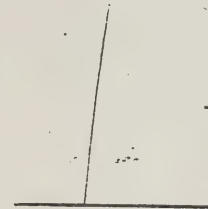
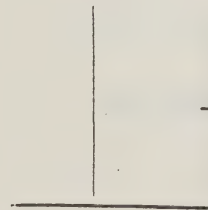
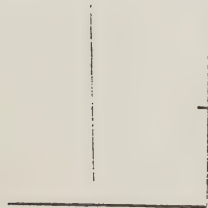
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APPENDIX 9

REVIEW OF THE OME MODEL FOR
LONG RANGE TRANSPORT OF
AIR POLLUTION

BY

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Dr. Venkatram's model (the OME model) is statistical in nature intending to have validity in terms of total depositions when averaged over long periods of time (> 1 year). It is essentially very simple and efficient in computer time.

In many respects such a model is extremely attractive since it permits tests to be made on the sensitivity of model-results to changes in basic parameters in a very cost effective way.

It also includes a representation of real wet-deposition processes which parallels my own treatment and which both Dr. Venkatram and I believe to be more physically realistic than methods used elsewhere.

On the whole the agreement between the wet depositions observed at various stations in Canada and the USA and model-predicted values is encouraging. Nevertheless it has to be remembered that, by the very nature of the source distribution (i.e., that source strengths are very high in some areas and very low in others) and of the loss processes (which are statistically greatest in the first few hundred kilometres of travel), even the crudest of models tend to correlate modestly well with observations, although the degree of real physical sophistication may be quite low.

Taking perhaps the most extreme example of such a crude model, one may consider the correlation between observed (or implied) depositions within grid-squares and depositions assumed directly proportional to the emissions in the same grid-squares. In other words, in this model, the contribution to grid-square depositions from sulphur advected in from other squares is totally ignored! The effects of source-height variations from square to square are also ignored, as are air chemistry and a host of other factors normally considered.

Applying the approach to data for 1974 from 46 stations in western Europe, collected during the OECD LRTAP Experiment, correlations are found to be as follows:

1. the correlation between the total annual dry-deposition of sulphur inferred from observed SO₂ daily concentrations (and a constant velocity of deposition) and a model deposition, assumed proportional to the "same-square" emissions is for the 46 stations = 0.68.
2. the same but for wet depositions = 0.20.
3. the same but for total depositions (dry + wet) = 0.58.

Thus if total depositions are the objective such a "silly" model can give correlations with "observed" depositions which appear quite respectable and by which more sensible models have to be judged. Of course it

should be pointed out that, although the above correlations appear to be quite good, the actual deposition estimates themselves are not good: the emissions in the grid-squares, where the 46 monitoring stations existed, varied by nearly 3 orders of magnitude whereas the "observed" depositions vary only by 1 order of magnitude. Of course it is well known that correlations are dangerous indicators of model validity when taken on their own, and other more stringent tests should therefore be applied to Venkatram's results.

The development and application of any long range transport model of this kind explicitly or implicitly assumes something about the relationship between depositions and effects (to the receptor biosystems). In Venkatram's case the assumption is that damage occurs as a result of long-term average depositions. Whereas these averaged depositions are most likely to be important in some degree to some components of the damage problem, it has been argued (e.g., by P.F. Chester, 1981) that in other respects short-term deteriorations or "episodes" in lake and river water pH may be major determinants of fishlessness in certain areas of affected Scandinavia and America. If this is indeed so (and the evidence is quite strong that it is so) then some doubt must be cast on the usefulness of long-term statistical models of which the OME model is just one example: the source-receptor

relationships may be significantly different in kind when "episodes" alone are considered. Special conditions must make these occasions "episodes", and meteorology must play a major part in these.

The comparison of the OME model with the AES model shows rather considerable differences, albeit in the expected sense, namely that the contributions from distant sources to depositions are relatively higher in the OME model compared with those in the AES model (and vice versa). The AES model also seems to give higher wet depositions than the OME model. Large discrepancies of this kind are likely to lead to a weakening of your case in the American hearings. I feel that such differences should either be resolved, or a good case prepared to support the OME model values in comparison with other values.

The assumption of $v = 0$ in Venkatram's model is, as he well recognises, a present weakness. This is perhaps especially true of those occasions when significant rainfall occurs as the resulting wet depositions contribute so markedly to the long-term depositions.

Dr. Venkatram obviously would prefer to determine u and v by direct trajectory evaluation. Dr. B. Fisher, CERL, UK, is currently doing just this using trajectories

determined on a daily basis by the UK Meteorological Office for a power station plume in eastern England.

The following points can be made:

1. it is unlikely that u and v are the same for dry deposition and for wet deposition.
2. u and v may be different for normal wet occasions and for significant episodes.
3. several years data will be required to obtain reliable statistics, preferably supported by good daily air concentrations and deposition measurements.
4. a short term solution might be provided by selecting \bar{u} and \bar{v} to optimise the correlation between model and observed total depositions.

I suspect that geographical variations in rainfall are not included, nor are variations in rainfall probability with wind direction (this refers to Point 1 of the above paragraph, of course) or seasonal variations relevant to different snow/rain efficiencies in removing sulphur from the atmosphere. The first two are relatively easy to include (see for example Smith, 1981).

The model assumes a linear relationship between power station emissions and expected depositions. Is there in fact any evidence for this for large power stations at the ranges of concern? One might argue in the absence of real data that increasing sulphur emissions are likely to lead to increased heat emissions

which in turn may lead to an increased probability of mixing-layer-top penetration. If this were so then, out to ranges of one or two thousand kilometres, depositions might actually decrease albeit at the expense of higher depositions at really long range (in Europe and elsewhere, for example).

In summary, the OME model is a highly efficient and useful method for predicting LRTAP, although it also has some disadvantages and may lack important time resolution. Further development and verification of the model seems called for, but provided it is presented fairly and forthrightly it does seem to provide a reasonably good basis on which to argue Ontario's case to the American hearings.

References - Appendix 9

1. Chester, P.F., 1981. Acid rain, SO₂ emissions and fisheries. CERL Laboratory Note No RD/L/2122N81, CERL, Leatherhead, Surrey, UK.
2. Smith, F.B., 1981. Atmospheric Environment, 15, 5. pp 863-873. The significance of wet and dry synoptic regions on long range transport of pollution and its deposition.
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APPENDIX 10

REVIEW OF LONG RANGE TRANSPORT MODEL USED BY
ONTARIO MINISTRY OF THE ENVIRONMENT

BY

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JUNE 4, 1981

PREPARED FOR
THE MINISTRY OF THE ENVIRONMENT
THE PROVINCE OF ONTARIO

1. Introduction

1.1 This review of the long range transport model developed by the Ontario Ministry of the Environment is divided into two parts. The first three Sections discuss some general aspects of the model, its application and use, and a list of major conclusions. In an Appendix some technical details of the model are discussed and some suggestions for future work made.

1.2 The long range transport model developed by the Ontario Ministry of the Environment (MOE) has been used to assess how proposed changes in the sulphur emissions from 20 power plants in the United States would alter the rate of deposition of sulphur over regions of Ontario. This is a 'critical review' of this model and its application. It is critical in the best sense of the word, in that it attempts to show where the model is most successful and where it has limitations. There are a large number of models describing the long range transport of air pollutants and each has some advantages and some disadvantages. There is no one model which is so superior to other models that its use is to be recommended for all applications.

1.3 The review is largely based on material in three documents describing the model and the use made of it (Venkatram, Ley and Wong, 1981a, Ontario Ministry of Environment, 1981a and 1981b). The model has been used in the submission by the MOE to the U.S. Environmental Protection Agency (MOE, 1981b).

2. General Remarks

2.1 The model falls into the category of a statistical model. By this it is meant that the input parameters used in computations are statistical averages and do not describe the transport of pollutants on a specific meteorological occasion. By using statistically averaged quantities, the model enables long-term average concentrations, usually annual averages, to be calculated more efficiently than in other types of model, such as trajectory models. (In trajectory models the movement of air parcels along a trajectory is followed, and long term average concentrations are obtained by following a very large number of trajectories and then averaging). Because they avoid this computation, statistical models can be run more efficiently than trajectory models, allowing other aspects of the average behaviour of pollutants over long distances to be investigated in detail. For example, it is possible to run fairly

extensive analyses of the sensitivity of the model to changes in the values of the main parameters, (MOE, 1981a) an exercise which would be much more expensive with a trajectory model.

2.2 Comparison of statistical and trajectory models developed within the context of long range transport in Europe suggests that the models agree with each other and with measurements to within the limits of accuracy expected in modelling exercises (see Eliassen, 1978; Johnson, Wolf and Mancuso, 1978; Bolin and Persson, 1975; Fisher, 1978 and also the review of models by Eliassen, 1980). The same measure of agreement has not been reached in North American models (see paragraph 3.1 for further comments), but is expected eventually. This, of course, applies only to annual average concentrations or annual rates of deposition. For investigating case studies of long range transport, a trajectory model, or something like it, would be needed.

2.3 Modelling approaches developed in a European context may be applied to North America, since the general principles are the same, though there may be differences in climate, i.e., greater extremes or more persistence of certain conditions. This can be allowed for in the model by altering values of the

meteorological parameters in the model. The MOE statistical model uses commonly acceptable values for the main parameters and takes into account the main transformation and removal processes. It is therefore quite acceptable to use this model for calculating annual average concentrations and annual depositions of sulphur oxides. It uses techniques which are within the current state of the art regarding long range transport modelling. Its simplicity makes it attractive to users without easy access to meteorological data.

2.4 Further testing of the model against experimental data is recommended. In particular, atmospheric concentrations of sulphur oxides have not been compared with measurements. Such comparisons will become more valuable tests of the model once results from on-going and new monitoring networks become available in the next year or two. However, the sensitivity analysis of the model undertaken by the MOE (1981a) suggests that many of the derived quantities are insensitive to values of the parameters in the model, suggesting that the use of the MOE model in a relatively untested form is justified. Much work is underway at the MOE to investigate and it is hoped more fully justify, parameter values used in the model.

2.5 Some caution must be used before drawing conclusions from the model. This cautious approach has been shown in the paper submitted for publication in the scientific literature (Venkatram et al., 1981a) and in Chapter 7 of the submission to the U.S. Environmental Protection Agency (MOE 1981b) in which the error bounds on the results of the model are clearly stated. Though it is not possible to justify completely and objectively the accuracy of this and other models, one seeks to achieve an accuracy of $\pm 50\%$ in the estimates and this should always be borne in mind when stating results. Since the MOE model is a 'state of the art' model, this sort of accuracy is to be expected from it.

2.6 The above remarks apply specifically to the use of the MOE model to calculate the long range transport of sulphur oxides. No models for the transport of acidity have been developed, nor of the other species, (nitrate and ammonium) which determine the acidity of precipitation. Sources and removal processes for these substances are far less well understood than for sulphur oxides. Undoubtedly, the concentration of sulphate and nitrate in precipitation, and its acidity, are correlated, but the use of a single empirical relationship allowing the acidity of precipitation to be deduced from sulphate concentrations alone, is not generally

accepted at present. Further research on this aspect is urgently required, as well as clarification as to which is the most important quantity deposited from the atmosphere, influencing freshwater systems.

2.7 Another general problem is the assumption of linear conversion rates. One can invoke chemical arguments for supposing that the conversion rates are non-linear. However, most operational models use linear chemistry, with which they obtain reasonable agreement with measurements. This arises because the overall conversion is very slow, so that all reactions can be approximated by a linear rate constant. The use to be made of the model does not involve large changes from present emissions, for which satisfactory agreement with measurements has been obtained. It might be dangerous to extrapolate the model to circumstances when emissions were more than halved or doubled, since in these circumstances there is no guarantee that the linear assumption still applies.

2.8 These are probably the most general issues concerning the use of the model and apply, to some extent, to all operational long range transport models. In the Appendix, examples and amplifications of many of these points are given.

3. Application of MOE Model for Calculating Impact of
20 U.S. Power Plants on Deposition over Ontario

3.1 There is a large discrepancy between the predictions of the MOE model and the Atmospheric Environment Service (AES) trajectory model when both are used to calculate the same quantity (as an annual average) with approximately the same emission data. Broadly speaking the MOE model underpredicts wet deposition compared with measurements and the AES model overpredicts (US - Canada Memorandum of Intent, 1981). Venkatram et al., (1981a) argue that the wet deposition measurements used to test the MOE model are overestimates. An attempt should be made to reconcile the two models, since the differences are more than a factor of two, and could not be resolved by adjusting values of the parameters in the MOE model (see sensitivity analysis (MOE, 1981a)).

3.2 The differences are not only due to differences in the treatment of wet deposition since the same effect occurs with airborne concentrations. The differences are particularly marked regarding the contribution of Ontario sources to sulphur dioxide concentrations in sensitive areas of Ontario. The AES model appears to be overpredicting at distances up to several hundred kilometres from major source regions. An attempt should be made to resolve such

discrepancies within the Canadian research community.

3.3 The application of the MOE model to calculating the contribution from twenty U.S. power plants has been undertaken in a straightforward manner. It is a simple model and no obvious errors are apparent. The accuracy of the calculation is clearly stated.

3.4 In two ways the use of the MOE model may be misinterpreted in the submission to the U.S. Environmental Protection Agency (MOE, 1981b). Firstly, it is implied that the acid deposition can be inferred from the sulphur deposition, which cannot be done (see paragraph 2.6). Secondly, no conclusions about the effect of changes in stack height can be deduced from the model.

3.5 Further information should be supplied on the contribution from other sources, besides the 20 U.S. power plants under discussion, to deposition over sensitive regions of Ontario. This is illustrated in Table 1 below:

Table 1:
Percentage Contributions to Deposition
Over Muskoka-Haliburton Region of Ontario

	Wet Deposition	Total Deposition
All U.S. Sources	49%	55%
Ontario Sources	19	26
Other Canadian Sources	4	5
Background Contribution	28	14
Total Deposition (gS m ⁻² a ⁻¹)	0.7	1.4

In addition there will be a local contribution from sources within the region. The accuracy of the total deposition and individual contributions is ± 50%. This is based on results from the MOE model given in the February, 1981 Report under the U.S. - Canada Memorandum of Intent. Background refers to sulphur which cannot be directly related to sources within the region of study.

- 3.6 The sector analysis (Kurtz and Scheider, 1980) undertaken by the MOE appears to support the allocation to background of about one quarter of the

sulphur loading. The sector analysis also gives some support to the contributions allocated to sources in the United States. The Ontario contribution includes a contribution from Sudbury to the region of 10 to 15% of the total deposition and approximately the same contribution to the wet deposition (Venkatram, Ley, Wong, 1981b). Figures should be given of the local source emissions in the sensitive regions of Ontario and assessment made of their contribution. Thus a complete breakdown of contributions to the sulphur budget would be available.

- 3.7 Further dry deposition rates of sulphur which are probably comparable with wet deposition rates, should be stated explicitly, as well as projections of the effect of changes in emissions in the future from other sources besides the twenty U.S. power plants in question. In addition, the fraction of the emission from the power plants, deposited over Ontario or over sensitive regions in Ontario should be estimated. This information could be quite properly requested by interested parties. It is noted that emissions from twenty U.S. Power plants already exceed the amount allowable under 1979 Regulations.

4. Conclusions

- 4.1 The MOE model, within its limited of accuracy, is a satisfactory method of assessing the sulphur deposition over Ontario from 20 U.S. power plants and for estimating changes in deposition produced by changes in emissions (see paragraphs 2.3, 2.5).
- 4.2 There is no model available at present which can be used to predict acid precipitation (paragraph 2.6).
- 4.3 Further testing of the model against measurements is strongly recommended as the latter become available (see paragraph 2.4).
- 4.4 More results from the model should be presented in order for the complete budget of sulphur deposition over regions of Ontario to be assessed (see paragraphs 3.5, 3.6 and A.4). This may be requested by interested parties.
- 4.5 Further work underway at the MOE and elsewhere may help to refine the model and the choice of parameter values used (see paragraph A.2). So far this has not caused any basic changes to the model.

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Appendix

Technical Details of the MOE Model

A.1 We shall begin by discussing the appropriateness of parameter values used in the model. The removal of sulphur oxides by precipitation, whether in cloud droplets or raindrops, and whether the sulphur is in the form of gaseous SO_2 or as particulate sulfates, is the least well-known part of the problem. In order to obtain a sulphur budget for northwest Europe, in which measured and calculated rates of wet deposition are in approximate agreement, it is necessary to assume that the rates of removal of SO_2 and sulphate are fairly efficient processes. This assumption is made in the MOE model and is the only practical assumption in current operational models though it may not apply close to large point source emissions (Chan, Ro and Lusi, 1981). The exact values of the rates of removal of SO_2 and sulphate are not known with any certainty, but the deposition at long distances is insensitive to the exact values chosen, as shown by the detailed sensitivity analysis performed on the MOE model. This occurs because if a high value of a rate constant is chosen, this is compensated for by a correspondingly lower value for the amount of material travelling long distances.

A.2 Another problem with wet deposition is that it is very difficult to describe accurately the distribution of rainfall in space and time. Measurements of rainfall at meteorological stations only describe the broad features of a zone of precipitation ignoring the randomness of small scale features within it. For this reason the statistical treatment of periods of wet and dry weather used in the model is a reasonable compromise. The assumption of a uniform rainfall distribution at all points in the study area is a weakness, but recent work by Smith (1981) using a model virtually identical to the MOE model, but in which the probability of rainfall is allowed to vary in different regions, shows that solutions are relatively insensitive to variations in rainfall distribution. A directional dependence in the rainfall distribution could be tried in the model, but because of the insensitivity to parameter values would probably not change conclusions.

A.3 The (Lagrangian) durations of wet and dry periods are as important as the rate constants for wet deposition, in determining the overall wet deposition over the study area. The appropriate values of these parameters are hard to determine, since they require statistics of rainfall duration following the movement of the predominantly dry or

wet air masses. (This can be checked in the sensitivity analysis on the MOE model). The ratio of the durations is (approximately) equal to the fraction of the time it rains, so that these are not independent variables and should be adjusted separately in the sensitivity analysis.

A.4 The values of the rate of dry deposition of SO_2 and sulphate are known to greater precision than the corresponding parameters for wet deposition. Certainly the processes of dry deposition are understood more fully than the wet processes. The values chosen in the MOE model are a reasonable compromise between the values in the literature, which show considerable variability, and probably reflect real differences. However, rates of dry deposition from model calculations have not been presented (Venkatram et al., 1981a; MOE, 1981a). Though dry deposition rates are not measured directly, airborne concentrations of SO_2 and sulphate are, and these are proportional to the dry deposition rates. Thus both airborne concentrations and dry deposition rates should be derived from the model. The dry deposition is relatively insensitive to the dry deposition rate constants. The total deposition (dry plus wet deposition) should also be calculated. It may be an important factor in determining possible harmful effects. Estimates of

total deposition will ensure that a balance between emissions and deposition has been maintained. The total deposition is also relatively insensitive to the individual rate constants.

A.5 One would expect the conversion in the vicinity of the source regions to be higher than that at longer distances, since the concentrations of other pollutants and oxidising species is higher. This is taken into account in the MOE model, to some extent, by assuming that a fraction of the sulphur is emitted directly as sulphate. However, the fractional emission of sulphate is only 2% which is rather less than that found in European work, Smith (1975); Eliassen (1978). A value of 10% for the fractional emission of sulphate may be more appropriate.

A.6 So far no specific data on the average behaviour of air masses in the study area have been used in the model. This is the most obvious area where the model can be improved. However, it is noted that a statistical analysis of trajectories has already been completed and supports the existing parameterisation.

A.7 There is one effect in the MOE model that is not taken into account and that is the amount of deposition which occurs locally, that is within the

basic grid squares (of length 100 km) into which area sources and the output from the model are resolved. In order to derive deposition patterns on a scale less than 100 km another sort of dispersion model would be required. This means that at any measuring site the model will underestimate by an amount due to local sources. It is also necessary in long range transport models to allow for dry deposition which occurs within the grid square containing a source, before the emitted material spreads through the mixed layer. An adjustment in the actual source strength must be made, which is a function of source height. For low-level sources the effective source strength is 0.7 to 0.8 of the actual source strength, while for high-level sources, with lower ground level concentrations near the source, the effective source strength can be taken to be nearly equal to the actual source strength. The neglect of this effect in the MOE model when applied to power plants, is not important, but when applied to the total impact of regions it can be of some significance. As it stands the MOE model does not supply information on the relative importance of high and low level sources.

A.8 Some operational models allow the mixed layer depth to vary with time along a trajectory. This clearly

happens in reality - but since the MOE model is only used for averaged quantities the inclusion of such a detailed effect is not justified. In fact, more advanced models seem to support the use of simple models for operational purposes, provided the limited accuracy of such models is borne in mind and the quality of monitoring networks remains the same.

A.9 An important parameter in models of sulphur transport over long distances is the so-called "background" concentration of sulphate in precipitation. This is sulphur which cannot be directly related to sulphur emissions within the study area, but which can be an important fraction of the total wet deposition at sites remote from sources. The origin of this background is uncertain. It may be due to a global natural background, very distant man-made sources, material which leaves the study area and then returns after a long travel path or material which escapes into the troposphere above the mixed layer and is later involved in precipitation. The MOE model makes some allowances for this. Further investigation of wet deposition measurements at remote sites is required to establish more exactly the magnitude of this background. In the Muskoka-Haliburton region of Ontario it appears to represent 15-25% of the annual wet deposition.

A.10 It is important to test models against measurements. It has already been recommended that other outputs from the model, such as concentrations of SO₂ and sulphate should be used in this validation. Data from the CANSAP network appears somewhat suspect. Data from the Canadian Air and Precipitation Monitoring Network (APN) (Barrie, Wiebe, Fellin and Anlauf, 1980) should be used, when it becomes available, and data from American networks.

A.11 It is noted that the MOE, amongst other interested parties, is starting an extensive monitoring network related to acid precipitation across Ontario (Chan & Vet, 1981).

APPENDIX 11

A REVIEW OF
"A SUBMISSION TO THE UNITED STATES ENVIRONMENTAL
PROTECTION AGENCY OPPOSING RELAXATION OF
SO₂ EMISSION LIMITS IN STATE IMPLEMENTATION
PLANS AND URGING ENFORCEMENT"

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I

Introduction

In March, 1981 the Province of Ontario provided the U.S. Environmental Protection Agency with a report entitled "A Submission to the United States Environmental Protection Agency opposing the Relaxation of SO₂ Emission Limits in State Implementation Plans and Urging Enforcement". This review of the submission and supporting documents was funded by Ontario with the objective of providing an unbiased technical examination of the report's contents and conclusions. The Ontario submission provides background descriptions of issues and a discussion of Ontario's interest and legal position on the issues. Technical components of the report cover the causes and effects of acidic deposition in Ontario, the significance of emission increases at the plants in question, and Ontario's own mitigation efforts. The scope of this review is directed by the author's area of expertise in long range pollutant transport modeling and analysis. Topics included in the review are:

1. Long range pollutant transport relative to the northeast United States and Ontario
2. Analysis techniques used by Ontario in their submission
3. Data available for analysis
4. Validation of analysis techniques
5. General use of the Ministry of Environment simulation model in pollutant deposition studies.

In the course of the review the author was provided free access to information used by Ontario in preparing their report. This includes support documents, references and discussions with the staff of the Ministry of the Environment (MOE).

II Summary

In the following sections the review of the Ontario submission and support documents touches on several technical areas, but concentrates on the adequacy of MOE'S statistical model in assessing probable effects of U.S. emission regulation relaxation. A determination of adequacy implicitly supports the contention that increasing regional SO₂ emissions does influence Canadian air quality.

The following comments summarize the author's review of the Ontario analysis:

The interboundary transport of pollutants is real and several studies support Ontario's view that the U.S. sources significantly influence Ontario air quality.

Two approaches have been considered in explaining observed long term deposition patterns. The first suggests that deposition is controlled by the distribution of pollutants. The second downplays the air concentration patterns and indicates that deposition is

dominated by precipitation patterns given a sufficient pollutant mass. Ontario takes the first approach and presents a valid argument in stating that an increase in emissions in the region of contention will increase pollutant impact in Ontario. This is supported by studies simulating direct plume transport including those represented by MOE'S model results. Recent studies indicate that wet deposition rates for acidic species over long term periods are controlled by transformation and removal processes and patterns of precipitation thus following the second approach. It is not clear that this concept would yield significantly different conclusions on the impact of emission changes. Evidence is not available to determine if sufficient pollutant mass is always present to provide the maximum deposition possible in a storm. If scavenging is less than maximum, then increases in emissions and therefore concentrations would also increase deposition.

Ontario has provided an assessment analysis using a simplified statistically based model. The model formulation accounts for the most important aspects of long range sulphur oxide transport including transformation and removal. These are simulated in a physically realistic manner consistent with models and assumptions of other investigators. The model clearly has limitations but gives reasonable estimates of levels of long term pollutant concentrations and deposition values

which are supported by limited verification studies. Sensitivity tests indicate that some variations in concentration and deposition patterns which the model is unable to simulate may cause significant deviations from the long-term mean values. These do not negate the value of the MOE estimates, but do show areas for model improvement.

Ontario stated that ecological impacts are primarily caused by short-term heavy summer showers and spring run-off. This suggests that MOE may not have used an appropriate model since only long-term averages were simulated. It is expected that a shorter term model would indicate higher impacts in Ontario's ecologically sensitive areas than those presented.

III Long Range Pollutant Transport in the Northeastern United States and Ontario

The MOE'S discussion of emissions changes concentrates on long range transport of sulphur dioxide (SO_2) since it is this pollutant whose emissions are subject to change of the United States relaxed emissions limitations. Also sulphur oxides appear to be the dominant controlling species in both acid deposition problems (McNaughton, 1981) and in visibility reductions due to small particles (Lyons et al., 1978). The submission makes the valid point that there is

significant long range transport of pollutants across the U.S./Canadian Border. Investigators have indicated that transboundary pollutant transport is significant. For example, Shannon (1981) attributes equal contributions from the U.S. and Canada to Ontario's acidic deposition. The Ontario submission also documents transboundary pollutant transport and has used previous studies (e.g., Kurtz and Scheider, 1980) to identify broad source areas.

The report goes on to describe the use of a statistical model to simulate transport in the regional air shed encompassing Ontario and most of the northeast United States. This model is described in the following sections. Much has been reported on the inaccuracies of methods used to identify pathways for pollutants from sources to affected receptors, as well as whether patterns of acid rain are due primarily to rainfall patterns or air concentration patterns defined by the pathways. The Ontario submission is a reasonable attempt to estimate pollutant pathways using a valid technique.

The alternative, estimating deposition based primarily on rainfall patterns scavenging a regional airshed, was discussed by Wilson et al., (1980). It suggests that over long time periods rainfall patterns control wet deposition as long as a sufficient pollutant mass is available. In this reference, they do source/receptor

trajectory studies, but explain that sufficient data is not available to show pathways. Although it was not used in the MOE model, the regional air shed concept should not be dismissed, since the importance of precipitation patterns has been acknowledged. One suggestion for improving the MOE model, which will be discussed in Section 4, is to add spatial variability to precipitation related parameters and therefore increase precipitation dependence.

The unresolved question in current analyses of the regional airshed idea is whether concentration levels now exist which represent the maximum rate controlled levels for formation and deposition. Ontario states correctly that it shares the airshed with the highly developed U.S. emissions areas in which SIP changes are proposed. If concentrations are not at the rate controlled level, then any increase in emissions in the airshed will impact Ontario.

IV Simulation Techniques Used by Ontario in
Assessing the Impact of State Implementation
Plan (SIP) Revisions.

Two basic approaches have been used in long range pollutant transport modelling. The first simulates transport for a sequence of short term meteorological conditions and accumulates the results (i.e., McNaughton,

meteorological data and performs calculations to directly simulate mean concentration and deposition. The statistical modelling approach was used by the Ontario Ministry of the Environment for their study (MOE, 1981).

Both models have advantages, and hybrid versions have been developed to make full use of model capabilities (Shannon, 1981). The MOE statistical model offers the user a large degree of computational efficiency, but has the disadvantage of requiring analysis of data bases collected over long periods of time to obtain fully representative parameters. It also is limited to providing concentration and deposition for the time period represented by the statistical parameters. The MOE model results represent annual concentrations over a number of years and could only be rigorously verified using a long term (i.e., approximately 5-10 year) data base.

This section is a review of the MOE model and its use in the submission to EPA. Subsections consider model input data, model formulation, model testing, and the applicability and use of the model in the SIP revision assessment.

4.1 Model-Input-Data

The statistical nature of the MOE Model limits the input data required for simulations to emissions data and various parameters. Statistics for the mean transport of pollutants (i.e., mean trajectories and spread statistics), the frequency and duration of rainfall, and other parameters deposition representing plume dispersion, chemical transformations and pollutant deposition were selected primarily from values given in the technical literature.

Emissions inventory data for the Ontario study represent the best annual average data available. Unfortunately, the emissions data bases are not precise due to a number of causes:

- ° errors in the data
- ° uncertainty in natural emission/omitted pollutants
- ° use of crude emissions estimate techniques rather than measurements
- ° high year-to-year and short-term variability in real emissions due particularly to variability in plant operating schedules and fuel sulphur content.

As a result, assessments made using this data should be evaluated with a clear knowledge that such an evaluation examines both the simulation model and the emissions data.

Various estimates of inventory error have been made which are probably applicable to the MOE analysis. Estimates of emissions for Europe are reported to an accuracy of 30% (OECD, 1979) while the best U.S. Regional Inventories differ by approximately 10% (Benkovitz, 1981) indicating error at least to that level. Natural contributions to sulphur oxide emissions may be significant in accounting for the origin of total atmospheric sulphur but in areas such as the Northeast U.S. the contribution is small (Rice et al., 1981). Natural and anthropogenic inventories of oxides of nitrogen sources appear to be less critical in the acid deposition estimates (McNaughton, 1981; Galloway and Likens, 1981) which is fortunate due to the lack of reliable data.

The Ontario analysis minimizes the impact of emissions errors and variability through the use of an incremental technique. The total SO₂ emissions inventory for 1979 is used to estimate sulphur deposition levels. The impact of modifying emissions regulations is examined by a comparison of deposition from the 20 plants under study in each scenario to the base case. Base emissions for the 20 plants under study were calculated using actual fuel consumption, heat content, and average fuel sulphur content values provided by the Federal Power Commission. Current and proposed State Implementation Plan emissions limits were added to the analysis using heat input data calculated with the 1979 FPC data and

applying the emissions limits. As a result, the reported differences in impact reasonably reflect the effect of the proposed emissions changes for the most recent year with complete data.

4.2 The-Model-Components

The MOE statistical model is made up of two components representing pollutant dispersion and scavenging by transformation and wet and dry deposition. The model components are independent probability density functions. The first assesses the probability, as a function of travel time that pollutants released from a point will be transported to a receptor. The second assesses the probability that a pollutant will be transformed or be scavenged. The probabilities are then multiplied and integrated over time to effectively distribute the emissions over the region of prediction.

4.2.1 Dispersion Component

Dispersion in the MOE Model follows the assumption that long term concentrations are insensitive to short term fluctuations in meteorology. This assumption, utilized by others (e.g., Shannon, 1981; Fay and Rosenzweig, 1980), can be expected to reasonably represent long term averages. The probability function for horizontal dispersion assumes that trajectories are

randomly distributed in the horizontal plane primarily as a result of large scale synoptic conditions. The distribution is defined by mean trajectory end points and standard deviations in the downwind and crosswind directions. These are applied uniformly to all sources regardless of location. The values of the parameters would ideally be calculated from long term measurements, but such a long term analysis has not been undertaken. Shannon (1981), who requires similar data, has selected a data set based on two years data and acknowledges the hazards of potentially unrepresentative data. The Ontario MOE makes reasonable assumptions based on values given in the meteorological literature. A report on regional scale climatological concentrations by Machta (1979) indicates that the values selected for mean wind direction are reasonable, although the mean wind speed is somewhat high. Sensitivity tests of the model indicate that use of a high wind speed would slightly modify deposition near sources resulting in increased deposition in western quadrants and decreased deposition in eastern quadrants.

In summary the dispersion calculations represent a simplified but valid approach to the problem of pollutant transport which compensates for a lack of long term data with carefully selected parameters.

4.2.2 Scavenging Component

The scavenging model has its basis in a number of previous models and is representative of the research direction of other investigations (e.g., Smith, 1981). The model is complete with its formulation including the emissions of the two predominant sulphur species and the simplified schemes to estimate dry deposition of pollutants, scavenging or removal by precipitation, and the chemical transformation from SO_2 to sulphate. In the model, different equations representing the conservation of material are written for SO_2 and sulphates depending on whether or not release was during wet or dry periods. The distinction between wet and dry periods is important in accounting for the change in removal parameters during rain. Conversion of mass under wet or dry conditions is accomplished by specifying a different mean time scale for each condition. The material conservation equations are solved analytically to provide convenient expressions for probability density functions which answer the question, "What is the probable fate of emissions after a specific travel time?".

Parameterizations selected by the Ontario MOE for scavenging, transformation and dry deposition parameters are those commonly used by other investigators (Husar and Husar, 1978). MOE recognizes the important distinctions among typically quoted values and attempts to avoid

problems associated with their use in a statistical model, particularly where over-prediction of removal is possible. Dry deposition rates are modified to account for the effect of diurnal change. SO_2 to SO_4 transformation rates used (1%), are reasonable except in representing transformation in clouds. MOE acknowledges the problem and accounts for it in a different manner than the author (McNaughton and Scott, 1980), but further research is required to establish the best method. A critical feature of this class of models is the duration of wet and dry periods. Values selected by the MOE are in the range of those identified in other data analyses (e.g., Henmi and Reiter, 1978).

4.3 Evaluation of the MOE Model

The Ontario MOE analysis of SIP emission limit changes makes use of a model which has been tested both to verify results and to investigate the sensitivity of results to model parameters selected for the study.

4.3.1 Model Verification

Results of the statistical assessment model have been compared to air concentration fields for sulfates as well as deposition patterns. SO_2 patterns were not examined due to the high local variability of concentration patterns which are not adequately simulated by the model.

Modeled annual air concentration patterns for sulfates were compared to data from nine U.S. sites with data from the Sulfate Regional Experiment (Misra, 1981). The model generally under-predicted sulphate concentrations but all concentrations were within a factor of two. No other meaningful performance statistics for concentrations were available due to the small sample size.

Deposition data from the MOE model were compared to contours of deposition compiled by Galloway and Whelpdale (1980) from a number of measurement programs. In general, the model underpredicted deposition, but a consistent and complete comparison of observations to predictions was apparently nullified by questionable data quality and/or consistency.

The deposition data and concentration data examined do show a general and significant pattern of model under-prediction. It is interesting that Shannon (1981) observed the same under-prediction problem with a hybrid statistical model as did McNaughton (1980) with a sequential trajectory model. McNaughton and Scott (1980) later found that they would avoid the under-prediction of deposition by a consideration of incloud conversion of SO_2 to sulphate.

4.3.2 Model-Sensitivity Tests

Model sensitivity tests study the effects or sensitivity of changes in model parameters. They are very beneficial in understanding the complex interactions of parameters presented by the models. The MOE statistical model was tested for the sensitivity of wet deposition to 15 parameters. The model was found to be most sensitive to parameters which have to do with the amount of pollutant available for removal. These are wind speed, wind direction and spread statistics since they relate to getting the pollutants to a receptor. Also, it is sensitive to SO₂ wet and dry scavenging parameters as they determine the mass of sulphate which can be formed and removed.

Examination of sensitivity tests by the author does not suggest obvious differences from other models in terms of parameters. Similar models by Smith (1981) and Shannon (1981) do show a directional sensitivity which might impact MOE model assessments. Shannon with a statistical transport module indicated that year to year changes in specified wind data could result in a 9-30% change in pollutant flux over the U.S./Canadian border. Smith stresses the importance of describing the non-uniformity in precipitation fields. These tests suggest that year-to-year and shorter term fluctuations represented by spatially varying parameters may result in

deposition patterns which could be higher or lower than those presented in the submission.

4.4 Use of the Ministry of the Environment Statistical Model in the Long Range Transport Assessment

The MOE statistical model provides estimates of long term concentrations of SO₂ and sulphate in air, as well as deposition estimates. The previous section indicated that the model has reasonable success in prediction, but quantitative verification statistics could not be calculated. The available verification data are not sufficient to provide long term averages comparable to the model. In addition, little or no valid dry deposition data are available. However, in light of the model performance record and the model formulation, the author feels that the model used can provide estimates of long-term pollutant averages.

In the Ontario submission, emphasis was placed on ecological effects due to deposition of acidic species. The ecological effects quoted in the submission are primarily a result of acidity changes in lakes due to pollutant scavenging in short term summer showers and acidic spring runoff. The runoff represents a somewhat longer term effect, as a result of the accumulation of pollutants dry deposited on winter snow fields, with wet

deposition occurring by winter precipitation. Estimates of pollutant impacts in both of these applications may be misrepresented using the MOE model since they are short-term questions. Annual average concentration and deposition values given by the MOE model would probably under-estimate maximum short-term impact of increased emissions from southerly sources. This hypothesis should be tested with a modification of the MOE model or use of another model to better match the time scales of model predictions to impact periods of interest.

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APPENDIX 12

SUDBURY ENVIRONMENTAL STUDY

A STATISTICAL MODEL TO ESTIMATE
LONG TERM CONCENTRATIONS OF POLLUTANTS
ASSOCIATED WITH LONG RANGE TRANSPORT
AND ITS APPLICATION TO EMISSIONS
FROM THE SUDBURY REGION

REPORT NO. ARB-36-81-SES

SEPTEMBER, 1981

MINISTRY OF THE
ENVIRONMENT ONTARIO

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A Statistical Model to Estimate
Long-Term Concentrations of Pollutants
Associated with Long-Range
Transport
and its Application to Emissions
For the Sudbury Region

by

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SUMMARY

A simple statistical model is presented for estimating long-term concentrations of pollutants associated with long-range transport. Dispersion and removal of pollutants are described in terms of statistics of these physical processes. The model has been used to estimate wet deposition of sulfur over a grid covering Northeastern United States and Canada and model estimates compare well to corresponding measurements of annual deposition. The model was then applied to estimate the relative contribution of major Sudbury region sulfur dioxide emitters, INCO and Falconbridge.

Four emissions scenarios were considered. First was the 'base case' emission inventory where INCO and Falconbridge's emissions were represented by 1977 amounts. Second was the strike/shut-down emission scenario and third was an SO₂ emission inventory based on the December, 1980 emission limits. The fourth inventory was calculated from Falconbridge's December 1980 emission limit and the August 28th, 1980 Control Order limit for INCO effective January 1, 1983.

The model estimate for the 'base case' emissions showed that the Sudbury region contributed 5 - 30% of the total sulfur deposited during precipitation in most of north-central Ontario and western Quebec. Falconbridge contributed 1 - 5% while the remaining portion was due to INCO's emission except for a small area and small-point source contribution which did not exceed ½%.

The second emission scenario was chosen to show the change in the long-term deposition of sulfur in rain that a reduction in emissions equivalent to the strike/shut-down emissions would cause. For this scenario total 1978 and 1979 emissions for INCO and Falconbridge were averaged to estimate an emission representative of this period. The model result for this scenario showed that the Sudbury region contributed 2 - 20% of the total sulfur deposited in rain in north-central Ontario and western Quebec. Similar reductions from the 'base case' are seen for the individual large emitters.

The emission inventory for the third case represented INCO and Falconbridge emissions by the December, 1980 maximum limits defined by their Control Orders. For this scenario Sudbury's contribution to deposition in north-central Ontario and western Quebec was estimated to be approximately 3 - 25%.

The fourth scenario modeled the long-term contribution of major Sudbury emitters assuming INCO's emissions are the maximum allowable as of January 1, 1983. The results of this simulation showed in north-central Ontario and western Quebec emission from the Sudbury region would have contributed 2 - 23% of the total sulphur deposited during precipitation. Reducing the model emissions for the Sudbury region from 1977 to projected 1983 levels decreased this area's contribution to wet deposition in Muskoka-Haliburton over a long time period by as much as 7% of the total 1977 wet deposition.

Care must be taken in the interpretation of these results. We emphasize that the model results are estimates of long-term long-range wet deposition rates expressed as annual amounts and should not be expected to compare well with measurements taken either near the emission sources or over short periods of time.

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INTRODUCTION

Several studies have shown that relatively simple models can provide acceptable estimates of long-term SO_2 and SO_4 concentrations associated with long-range transport. Using a numerically efficient statistical model Fisher (1978) has been able to compute sulfur deposition rates which are comparable to those obtained from models such as that developed by Eliassen (1978; see also Johnson et al., 1978) which require considerable more data input as well as computational effort. In a recent paper, Fay and Rosenzweig (1980) have shown that a simple analytical model based on the two-dimensional diffusion equation is capable of yielding SO_2 and SO_4 concentration estimates which compare rather well with measurements made over the United States. Thus, there is empirical evidence that simple models "work". The long range transport model presented in this paper is based on this idea. We will show that it incorporates useful features which represent improvements over earlier work.

Our model is statistical in the sense that the physics of transport is parameterized in terms of statistical parameters. The basic premise of this class of models is that long-term concentrations are insensitive to short-term fluctuations in meteorology. It is assumed that concentrations averaged over periods of the order of a year reflect "mean" patterns of the large scale meteorology. This allows us to take a simple approach to the modeling of long-range transport.

The model described in this paper consists of two components, namely the scavenging and the dispersion submodels, each of which will be described separately. Then we will demonstrate the use of the model by comparing wet sulfur deposition estimates with measurements presented by Galloway and Whelpdale (1980) and, finally, we will apply it to the estimation of the annual wet deposition of sulfur from emissions in the Sudbury region.

SCAVENGING MODEL

The treatment of the removal of sulfur is similar to that proposed by Rodhe and Grandell (1972) and used by Bolin and Persson (1975) and more recently by Fisher (1978). However, this submodel is more "physically" based and it will be seen that it is capable of handling more general physical situations than those by the model of Rodhe and Grandell (1972).

The model is based on the idea of classifying pollutant particles and "wet" and "dry". Wet particles exist during precipitation and dry particles during dry periods. On a long term, every travel time from a source is associated with a certain amount of dry particles and a certain amount of wet particles. Using this concept we can formulate differential equations for the evolution of these particles as a function of travel time from the source. Before doing so we will clarify a few concepts. Wet particles, released during precipitation, retain their identity until they encounter a dry period. Following Rodhe and Grandell (1972) we will assume that the average rate of "conversion" from wet to dry particles is inversely proportional to the average length of wet periods in a Lagrangian sense. A similar assumption can be made regarding "conversion" of dry particles to wet particles. Further, we will assume that the scavenging coefficients do not vary with travel time. However, they are different for wet and dry periods. If we denote SO_2 by G and SO_4 by S , their evolution can be conveniently shown in Fig. 1. In the figure, λ refers to the SO_2 scavenging coefficient, k is the SO_2 to SO_4 conversion rate, $\bar{\lambda}$ is the SO_4 scavenging coefficient, τ is the average length of wet or dry periods, and subscripts 'd' and 'w' refer to dry and wet particles. We see that the 'species' G_d (dry SO_2) is depleted through dry deposition (λ_d), conversion to sulfate (k_d) and conversion to wet SO_2 ($1/\tau_d$). We also note that wet SO_2 is converted to dry SO_2 at a rate given by $(1/\tau_w)$. The evolution of sulfate as a function of travel time is modeled in a similar manner. It is important to note that the particular form of the conversion from dry to wet particles or vice versa is based on the assumption that the cumulative frequency distribution of wet or dry periods is exponential (Rodhe and Grandell, 1982). From the diagram we can immediately write down the equations for G and S .

$$\frac{dG_d}{dt} = -\lambda_d G_d - k_d G_d - \frac{1}{\tau_d} G_d + \frac{1}{\tau_w} G_w \quad (1a)$$

$$\frac{dG_w}{dt} = -\lambda_w G_w - k_w G_w - \frac{1}{\tau_w} G_w + \frac{1}{\tau_d} G_d \quad (1b)$$

$$\frac{dS_d}{dt} = -\bar{\lambda}_d S_d + \bar{k}_d G_d - \frac{1}{\tau_d} S_d + \frac{1}{\tau_w} S_w \quad (2a)$$

$$\frac{dS_w}{dt} = -\bar{\lambda}_w S_w + \bar{k}_w G_w - \frac{1}{\tau_w} S_w + \frac{1}{\tau_d} S_d \quad (2b)$$

If Q_{SO_2} and Q_{SO_4} denote the amount of SO_2 and SO_4 released at the source we can write

$$G_d(0) = f_d Q_{SO_2}; \quad G_w(0) = f_w Q_{SO_2} \quad (3a)$$

$$S_d(0) = f_d Q_{SO_4}; \quad S_w(0) = f_w Q_{SO_4} \quad (3b)$$

In (3), f_d and f_w are the fractional dry and wet periods at the release point. With (3) the solutions of (1) and (2) readily follow

$$G_d = \sum_{i=1}^2 A_{di} e^{-\alpha_i t}; \quad G_w = \sum_{i=1}^2 A_{wi} e^{-\alpha_i t} \quad (4a)$$

$$S_d = \sum_{i=1}^2 B_{di} e^{-\gamma_i t} + \sum_{i=1}^2 \beta_{di} e^{-\alpha_i t}; \quad (4b)$$

$$S_w = \sum_{i=1}^2 B_{wi} e^{-\gamma_i t} + \sum_{i=1}^2 \beta_{wi} e^{-\alpha_i t}$$

Details of the solution are given in the appendix.

After writing this paper we learnt that F.B. Smith (1980) has developed a scavenging model based on equations almost identical to ours. In his paper he provides considerable physical insight into the meaning of wet and dry periods which determine the particle "type" as used in our model. He also considers the effect of the variation of rainfall rates on the evolution of G and S . The

significant conclusion of his study is that it is necessary to differentiate between mobile wet and dry synoptic regions in order to make realistic estimates of sulfur deposition.

It is seen from the formulation of the model that we can specify different removal rates for dry and wet periods. This can be useful in sensitivity studies. For example, it is easy to test the recent hypothesis (McNaughton and Scott, 1980) that the SO_2 to SO_4 conversion rate is higher during rain than during dry periods.

DISPERSION MODEL

The long-term concentration $\bar{C}(\underline{r}, t)$ at point \underline{r} at time t can be written as (Lamb, 1980)

$$\bar{C}(\underline{r}, t) = Q \int_{-\infty}^t p(\underline{r}, t | \underline{r}_s, t') dt' \quad (5)$$

where Q is the emission rate of the source located at \underline{r}_s and $p(\underline{r}, t | \underline{r}_s, t')$ is the probability density that a particle released at \underline{r}_s at time t' will be found at \underline{r} at time t . If we assume that p can be expressed as

$$p(\underline{r}, t | \underline{r}_s, t') = p(\underline{r} | \underline{r}_s; t - t') \quad (6)$$

Equation (5) becomes

$$\bar{C}(\underline{r}) = Q \int_0^{\infty} P(\underline{r} | \underline{r}_s; \tau) d\tau \quad (7)$$

Note that τ is the time of travel between \underline{r} and \underline{r}_s . To proceed further we will assume that scavenging and dispersion are independent. Fisher (1978) and Bolin and Persson (1975) have used this assumption in their models. This then allows us to express p as

$$P(\underline{r} | \underline{r}_s; \tau) = M(\tau) D(\underline{r} | \underline{r}_s; \tau) \quad (8)$$

where $M(\tau)$ depends only on removal mechanisms and $D(\underline{r} | \underline{r}_s; \tau)$ is a function of large scale dispersion. It is easy to see that $M(\tau)$ corresponds to the functions G_d , G_w , S_d and S_w (See Eq. 4) for unit release and is essentially the probability that a particle will survive after a travel time τ .

The dispersion function $D(\underline{r} | \underline{r}_s; \tau)$ will depend on large scale wind patterns. Bolin and Persson (1975) and Shieh (1977) have shown that the Gaussian puff equation is appropriate here

$$D(\underline{r} | \underline{r}_s; \tau) = f(z, \tau) \frac{1}{2\pi \sigma_x \sigma_y} \exp \left[-\frac{(x-\bar{x})^2}{2\sigma_x^2} - \frac{(y-\bar{y})^2}{2\sigma_y^2} \right] \quad (9)$$

where $f(z, \tau)$ describes the vertical dispersion. The parameters of the distribution $\bar{x}(\tau)$, $\bar{y}(\tau)$ are the co-ordinates of the mean particle position after travel time τ from the release point. The dispersion parameters $\sigma_x(\tau)$ and $\sigma_y(\tau)$ correspond to standard deviations of particles about (\bar{x}, \bar{y}) after travel time τ from the source. These parameters can be determined from trajectory statistics as suggested by Bolin and Persson (1975).

EMISSION INVENTORY

Figure 2 depicts the distribution and relative magnitude of the points which comprise the sulfur oxides in this study. The emission data for the model were collected from several sources. In the northeastern sector of the US it was compiled from the EPA point source inventories (Benkowitz; 1979) and the GCA (consulting company contracted by EPRI) major point and area source records. The Canadian emission points except in Ontario were taken from the AES preliminary point and area source inventory (Voldner et al., 1980). The Ontario points were extracted from the Ontario Ministry of the Environment sulfur emissions inventory.

Since we wished to limit the required computational resources, when feasible, we lumped sources together. All large (> 100 kTonnes $\text{SO}_2/\text{yr.}$) point sources listed in the above mentioned emissions data and 95% of the major (> 10 kTonnes SO_2/yr) point sources were incorporated into the model's inventory (usually grouped) to form effective point sources located at the emissions-weighted geometric means of the co-ordinates of the contributing points. Care was taken to amalgamate only sources situated in similar geographic settings and, in general, less than 50 km apart. Approximately 60% of all area emissions and 72% of all minor point emissions were incorporated into the inventory shown in Figure 2 by adding minor point sources and area sources located near (≈ 50 km) major points to that point or combining small sources concentrated in large urban centers to form effective point sources. Area emissions represent approximately 10% of the total emissions while small point sources account for about 17% of all SO_2 emissions.

SPECIFICATION OF DISPERSION PARAMETERS

The wet and dry deposition of sulfur depends on the vertical distribution of the pollutant as well as the turbulence in the diurnally varying planetary boundary layer. These factors have to be accounted for in modeling deposition and concentration fields averaged over time scales of the order of a day. However, Maul (1980) shows that estimates of annual averages of these variables are relatively insensitive to the details of the vertical concentration distribution. Furthermore, Eliassen and Saltbones (1975) and Johnson et al. (1978) have successfully predicted long-term averages, assuming that sulfur is well-mixed through a boundary layer which is invariant in space and time. On the basis of these studies we took the distribution of SO_2 and SO_4 to be uniform in the vertical through the depth of a constant mixed layer. We should point out that this limits the resolution of the model to distances of the order of 100 km from major sources. Closer to the sources the assumptions of this model may not be appropriate for estimating the local contribution of the emitter.

The large scale horizontal distribution of pollutants is determined by the parameters \bar{x} , \bar{y} , σ_x and σ_y . For the co-ordinates of the mean motion of large scale eddies we assume that

$$\begin{aligned}\bar{x} &= u \tau \\ \bar{y} &= 0\end{aligned}\tag{10}$$

where u is the mean velocity of synoptic eddies and τ is the travel time from the source. Equation (10) expresses the fact that at mid-latitudes weather systems move from the west to the east. Fay and Rosenzweig (1980) have used this assumption in their modeling exercise.

The analysis of trajectories by Slinn et al. (1979) and Bolin and Persson (1979) suggests that σ_x and σ_y can be expressed as

$$\begin{aligned}\sigma_x &= \sigma_u \tau \\ \sigma_y &= \sigma_v \tau\end{aligned}\tag{11}$$

On the basis of statistical dispersion theory it is reasonable to assume that σ_u and σ_v are the standard deviations of the horizontal velocity fluctuations of synoptic

turbulence. These statistics could be derived by sampling 850 mb winds over periods of the order of years. Tennekes (1977) suggests the following values for the large-scale velocities

$$u = 10 \text{ ms}^{-1}, \sigma_u = 10 \text{ ms}^{-1}, \sigma_v = 6 \text{ ms}^{-1}$$

We should point out that our choice of the horizontal dispersion parameters is tentative. They will be modified when we have completed a statistical analysis of trajectories.

SCAVENGING PARAMETERS

The stochastic scavenging model allows us to distinguish between wet and dry periods. This, as we shall see later, is a useful feature of our long-range transport model.

The transformation of SO_2 to SO_4 is a complex process which depends on a number of physical variables such as solar intensity and ambient ozone concentration, (see Wilson and Gillani, 1979). For long-term modeling we assume that the conversion rate is 1%/hr, a value which is an "average" of field measurements made during dry periods (Wilson and Gillani, 1979).

Our knowledge of the conversion of SO_2 to SO_4 during rain is almost non-existent. There is some indirect evidence (McNaughton and Scott, 1980; MacCracken, 1978) to indicate that incloud conversion of SO_2 to SO_4 can be greater than 10%/hr. Scott (1980) suggests that more than 60% of the sulfur in rain falling in summer is associated with SO_2 . The it is reasonable to assume that the rate at which SO_2 appears as sulfur in rain is limited by the rate at which SO_2 is incorporated into precipitating clouds. The rate at which clouds take up the SO_2 is approximately given by w/z_i where w is the mean updraft velocity at cloud base and z_i is the mixed layer height. w is given by (Smith and Hunt, 1979)

$$w = \rho_w R / M \quad (12)$$

In (12), ρ_w is the density of water, R is the precipitation rate and M is the water content of the air entrained into clouds. Typical values for these variables are $M = 5 - 10 \text{ gm}^{-3}$, $R = 1 \text{ mm/hr}$ and $z_i = 1000 \text{ m}$. We then find that the "effective" washout rate w/z_i for SO_2 is $\approx 3-6 \times 10^{-5} \text{ s}^{-1}$. This suggests that one way of accounting for incloud oxidation of SO_2 to SO_4 is to add an effective washout rate to the actual wet removal rate of SO_2 . An alternative is to increase the oxidation rate during precipitation. McNaughton and Scott (1980) found that a 10%/hr rate was necessary to explain measurements of sulfur in rain.

Washout of SO_2 is a reversible process which is a function of pH of rain. The washout rate decreases with pH. For the range of pH (4 - 5) usually encountered the scavenging rate denoted by j is of the order of 10^{-5} s^{-1} (Garland, 1978). Johnson et al. (1978) use a value of $6 \times 10^{-5} \text{ s}^{-1}$ ($R = 1 \text{ mm/hr}$) in their modeling study while Fisher (1978) is forced to use 10^{-4} s^{-1} to explain the measured values of wet deposition. These relatively high values for j are a consequence of additional

"washout" associated with incloud conversion of SO_2 to SO_4 . We feel that using an increased washout for SO_2 is the most convenient way to account for incloud oxidation. Increasing the conversion rate during precipitation (McNaughton and Scott, 1980) has the unrealistic feature of enhancing the sulfate concentration in the boundary layer.

Maul (1978) has inferred the value of the SO_2 washout coefficient from a time series of ambient SO_2 concentrations. He found that j could be described by the equation

$$j = \alpha R \quad (13)$$

where $\alpha \approx 3 \times 10^{-5}$. The linear dependence of j on R as well as the magnitude of α suggests that the "apparent" SO_2 washout could be dominated by incloud oxidation of SO_2 . This idea appears to be supported by the work of Eliassen and Saltbones (1975) in which sulfur concentration in rain is related to SO_2 rather than SO_4 concentration. The effective j used in their study is $\approx 4.0 \times 10^{-5}$. On the basis of these cited values for j we used $3 \times 10^{-5} \text{ s}^{-1}$ in our work.

The precipitation scavenging of sulfate is represented by a linear removal rate \bar{j} . This assumption used by several authors (Fisher, 1978; Johnson et al., 1978) is clearly unrealistic for modeling precipitation events. However, it is probably less critical for long-term estimates of wet deposition. In our study we used 10^{-4} s^{-1} on the basis of Garland's review paper (1978).

Measurements indicate that the dry deposition velocity v_d of SO_2 is of the order of 1 cm s^{-1} during daytime. As suggested by Fisher (1978) we used $v_d = 0.5 \text{ cm s}^{-1}$ to compensate for reduced deposition during stable nocturnal conditions.

Sulfate is primarily in the form of aerosol whose median diameter is below $1 \mu\text{m}$ (Garland, 1978). For this particle size range the deposition velocity is around 0.1 cm s^{-1} . We used $\bar{v}_d = 0.05 \text{ cm s}^{-1}$ for the reason given in the preceding paragraph.

We have little guidance on the magnitude of the parameters τ_d and τ_w . As they are Lagrangian variables defined with respect to trajectories of air parcels they cannot be derived from routinely available Eulerian (fixed point) meteorological observations. Rodhe and Grandell (1972) have estimated these parameters assuming a ratio between fixed point and Lagrangian measurements.

Slinn et al. (1979) have made more reliable estimates based on actual trajectories originating from Kansas city. The averages of the January and July 1975 values are $\tau_d=46$ hours and $\tau_w=7$ hours which are comparable to those suggested by Rodhe and Grandell (1972). Our studies showed that model results are relatively insensitive to τ_d and τ_w , a conclusion which is in agreement with that found by Smith (1980).

Table 1 presents the model parameters used in our simulations. The values of f_d and f_w are similar to those used by Fisher (1978).

MODEL TESTING

The model described in the previous sections has been used to compute sulfur in rain falling over the grid system shown in Fig. 2. The long-term sulfur deposition has been computed from

$$D_w = \left[\frac{1}{2} \bar{C}_{SO_2}^j + \frac{1}{3} \bar{C}_{SO_4}^j \right] z_i \quad (14)$$

Figure 3 shows contours of D_w obtained from the model. The emission inventory used corresponds to the year 1977. The figure also shows the locations of monitors set up by Canada and the United States to sample precipitation chemistry. The description of the network and the corresponding annual deposition values are given in the paper by Galloway and Whelpdale (1980).

Table 2 presents the comparison between the model predictions of sulfur wet deposition and the observations. Based on values suggested by Fisher (1978) we used a background deposition of $0.2 \text{ gm}^{-2}\text{s}^{-1}$. It is seen from the table that model predictions of wet deposition in the CANSAP (Whelpdale and Berry, 1978) network are generally lower than the observed values. However, the model explains 76% of the measured variance in the deposition. Rejecting the value at receptor 11 as an outlier increases the r^2 to 0.84. According to Whelpdale (personal communication) the measurement technique used in the CANSAP network might have led to an overestimation of the observations by about 30%. This should explain the predictions being lower than the measured values. It is interesting to find that regressing predictions against observations reduced by 30% results in $a = 0.17 \text{ gm}^{-2} \text{ yr}^{-1}$ and $b = 1.04$ (regression coefficients).

The ratio of observations to predictions for the American data is distributed fairly evenly around the ideal value of unity. However, the r^2 is insignificant at 0.09. Removing the outliers at receptors 24, 25, 26 results in a marked increase of the r^2 to 0.47. We believe that the discrepancy between model estimates and measurements is related to the fact that the American data have been drawn from a number of sources which are not likely to be consistent in quality (Galloway and Whelpdale, 1980).

Note that model testing is anything but straightforward. This is because the correspondence between model predictions and observations is very difficult to establish. The model estimate is designed to correspond to the mean of the concentration distribution to which the measured value is assumed to belong. Therefore, we expect model predictions to deviate from observations. At the present time we have little information on this expected deviation and we cannot avoid a certain degree of subjectivity in evaluating model performance. For a discussion of this problem the reader is referred to Venkatram (1979).

The classification of "outliers" in the data is not based on an objective criterion. But then we have rejected only 4 out of 26 points. It is useful to point out that 77% of the observations are within a factor of two of the predictions. Based on "experience" with air pollution modeling we believe these model estimates of wet deposition of sulfur are acceptable.

We should point out that model parameters used in this paper represent "standard" values quoted in literature (See Eliassen, 1980, for a review). We did not drive optimum values by "fitting" observations to model predicted depositions. This we believe lends credibility to the evaluation of the model.

EXAMPLES OF MODEL APPLICATIONS

The model can be used to estimate dry deposition. However, since lack of data would not allow testing of model calculations, we have chosen to show only examples of applications of wet deposition estimates. Before doing so, we should point out an interesting aspect of sulfur deposition. Figure 4 shows the contribution of SO_2 to the total wet deposition of sulfur. It is seen that wet deposition of sulfur is dominated by the apparent washout of SO_2 . This is clearly at variance with measurements (Dana, 1980) which indicate that SO_2 contributes no more than 40% to the sulfur in rain. However, the result tends to support the theory that incloud oxidation of SO_2 to SO_4 is very important. As mentioned earlier the simplest method of including this process in a model is to use a high "apparent" SO_2 washout rate. It is interesting to note that other modelers (Fisher, 1978; Johnson et al., 1978) have used SO_2 wet removal rates which are comparable to that used by us.

Figures 5 and 6 show the relative contributions of the U.S. and Canada to the wet deposition of sulfur. This type of information is useful for abatement plans in relation to the acid rain problem. It is seen that south of latitude 45° more than 50% of the sulfur deposited in rain can be attributed to U.S. sources. Canadian sources in Sudbury and Noranda are major contributors primarily in regions in their vicinity. Note that background deposition of $0.2 \text{ gm}^{-2}\text{yr}^{-1}$ is dominant in Northern Canada.

ESTIMATED ANNUAL WET SULFUR DEPOSITION DUE TO EMISSIONS FROM THE SUDBURY REGION

Sulfur dioxide emissions in the Sudbury region are dominated by two major emitters, INCO and Falconbridge. During the mid-1970's these sources combined to emit approximately 1340 thousand, metric tonnes of sulfur dioxide annually. Figure 7 depicts of sulfur dioxide emissions from Falconbridge and INCO during the past ten years. From this data the 1977 emissions were selected as representative of the mid-1970's time period and, therefore, compatible with available emissions data for other sources in northeastern North America. Emission inventories for long-range transport modeling always contain somewhat historical (3 - 6 years) data due to the large volume of data and the many agencies involved in their collection and preparation.

The statistical model described and evaluated earlier in this report will now be used to analyse several emission scenarios. For this study the wet deposition of sulfur from sources in the Sudbury area will be estimated using the model parameters summarized in Table 1. However, before proceeding to describe the model results we will briefly discuss the temporal and spatial scope of the model with reference to the major emitters in the Sudbury region.

The statistical model is based on the assumption that annual average meteorology can be used to describe long-term advection and dispersion of the pollutant. Intuitively this seems correct and the success with which the model estimates compare with the corresponding measurements of annual wet deposition of sulfur (Table 2) gives substance to this theory. However, the process of averaging removes short-term and small scale events and, as a result, the model only provides an estimate of average deposition over periods of the order of a year. Consequently all emission scenarios selected for Sudbury region have been chosen to represent long-term average emissions. For example, the regional emissions for the 1978-1979 strike/shut-down period will be represented by the two-year annual average emission while the actual emissions may have varied from almost no emissions to nearly full production.

The current model parameterization assumes instantaneous vertical homogeneity with all the pollutant emitted into the mixed layer. As a result, all processes or events occurring on the time/space scales less than those required for mixing to vertical homogeneity cannot be resolved by this model. The assumption of instantaneous vertical homogeneity is particularly questionable near the INCO, 381 m chimney which, in 1977, emitted approximately 80% of the Sudbury region's

SO₂ emissions. Frequently plumes released at this height are trapped above the mix layer and may travel large distances before being vertically dispersed.

Four emission scenarios will now be discussed. First will be the 'base case' emission inventory where INCO and Falconbridge's emissions are represented by 1977 amounts. Second will be the strike/shut-down emission scenario and third will be an SO₂ emission inventory based on the December, 1980 emission limits. The fourth inventory will be calculated from the current emission limit for Falconbridge and the August 28th, 1980 Control Order limit for INCO effective January 1, 1983. These emission scenarios are summarized in Table 3.

Figure 8 displays the model estimate of the relative contribution of sources in the Sudbury area to the total wet deposition of sulfur assuming the 'base case' emissions for INCO and Falconbridge. The relative contribution of the Sudbury region is the ratio of the wet deposition of sulfur due to INCO, Falconbridge and other regional sources and the total wet deposition due to all sources in northeastern North America. The model estimate of the total wet deposition of sulfur due to all sources is shown in Figure 3 and is discussed earlier in this report. The relative deposition patterns for INCO and Falconbridge are displayed separately in Figures 9a and 9b respectively.

The model estimate shows sources in the Sudbury region contribute 5 - 30% of the total sulfur deposited during precipitation in most of north-central Ontario and western Quebec. Near Sudbury the model predictions exceed 30%; however, as discussed earlier this close to the source the long-range transport model is no longer applicable. Comparison of Figures 8 and 9a show that during the mid-1970's INCO's emissions dominated the wet deposition due to sulfur emitted from the Sudbury region. However, Falconbridge (Figure 9b) did contribute a significant amount (1 - 5%) of the total sulfur deposited during rain in the central and northern portions of Ontario and in western Quebec.

Sulfur dioxide emissions from the Sudbury area were greatly reduced by shut-downs and strikes during the 1978-1979 period. To provide an estimate of the influence of this reduction on the long term pattern of wet sulfur deposition we calculate next the relative deposition pattern for Sudbury using INCO and Falconbridge two-year average annual emissions for 1978-1979. When calculating the relative deposition amounts the total wet deposition of sulfur from all northeastern North American sources is re-evaluated to reflect the reduced emissions from the Sudbury area but all other emissions are assumed unchanged from their 'base case' values.

The results of this reduced emissions scenarios are shown in Figure 10 and the individual relative contributions of INCO and Falconbridge are depicted in Figures 11a and 11b respectively. The effect of essentially halving the regional SO₂ emissions is obvious from the comparison of Figures 8 and 10. The model estimates show a reduction in wet sulfur deposition from 5 - 30% for the 'base case' to 2 -20% for the reduced emissions scenario over approximately the same region of north-central Ontario and western Quebec. The intent of this scenario is not to model deposition measurements during the strike/shut-down period since reductions in emissions during this time occurred as intervals of limited or no emissions rather than as an average decrease over the entire period. What the simulation does show is the change in the long-term deposition of sulfur in rain that an effective halving of Sudbury SO₂ emissions would cause.

The third Sudbury region emission inventory was determined from the December, 1980 maximum emission limits of both INCO and Falconbridge. Based on these Control Orders the maximum annual emission was calculated assuming the daily maximum was emitted 365 days of the year. For Falconbridge the limit was 465 short tons of SO₂ per day and for INCO (subject to the August 28th, 1980 Control Order) it was 2500 short tons SO₂ per day. Figure 12 depicts the model estimate of the relative deposition pattern for this scenario. As well, for comparison, the relative contributions of INCO and Falconbridge are shown in Figures 13a and 13b respectively. The patterns for this emission inventory represent the maximum contribution of current Sudbury emissions to the long-term average deposition of sulfur at large distances from the emitters. Actual annual emissions are expected to be somewhat less than this limit; hence, Figures 12 and 13 may be considered to present the current upper-bound on the long-term average wet sulfur deposition from Sudbury sources. This upper limit is subject to the assumption that emissions from all other sources have not changed significantly since the mid-1970's.

The final emission scenario considered is based on the maximum allowable SO₂ emission for INCO after January 1, 1983 as defined in the August 28th, 1980 Control Order. For this emission inventory we assume that Falconbridge's emission is the maximum currently allowed while all other sources are assumed unchanged from their mid-1970's annual emission rates. The exception being INCO whose annual emission is assumed to be 1950 short tons of SO₂ per day for 365 days per year. The results of this simulation are shown in Figures 14 and 15. Assuming no change in the magnitude of other sources the pattern in Figure 14 represents an estimate of the maximum contribution of Sudbury region sources to long term average deposition of sulfur during precipitation when INCO is subject to the January 1, 1983 sulfur dioxide emission limit.

CONCLUSIONS

We have shown that a simple statistical model can provide acceptable estimates of sulfur deposition. This supports the conclusions of the studies by Fisher (1978) and Fay and Rosenzweig (1980).

Our study indicates that SO_2 could be a major contributor to the wet depositon of sulfur. This appears to support recent indirect evidence of rapid incloud oxidation of SO_2 and SO . If this is indeed physically correct we can simplify modeling by concentrating on SO_2 .

Wet sulfur deposition in central and northern Ontario and Quebec from Canadian sources is dominated by SO_2 emitted by major smelting plants in Sudbury, Wawa and Noranda (See Figure 5). In the preivous section model calculations of the contribuiton of sources in the Sudbury region are presented for several emission scenario to estimate the long-term effect of reduced emission amounts. Comparison of these scenarios shows that reducing emissions from Sudbury would significantly reduce this region's contribuiton to the total deposition of sulfur during rain; however, Sudbury area emissions still would remain a major contributor along with Wawa and Noranda to deposition in the non-industrial area of north-central Ontario and western Quebec.

These modeling results were determined based on the premise that long-term SO_2 and SO_4 concentrations are related to the "average" meteorological conditions (were the averaging time is of the order of years). As a result the model calculations are not comparable to experimental measurements made over relatively short periods of times when the weather conditions may deviate significantly from the "average". For example, the model results are not directly comparable with the results from field experiments for relatively short term events such as the shut down of INCO in Sudbury between September, 1978 and June, 1979.

We realize that some of the assumption used in the model are questionable. For example, the statistics of disperison are not based on the analysis of trajectories. This analysis is in progress. Although model parameters are based on values quoted in literature we would like to perform a detailed sensitivity study in the future. Also we plan to incorporate the effect of source height into the model.

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Table 1

Model parameters used in "base" case simulations

1. Scavenging parameters

SO ₂ dry deposition velocity (v_d)	= $0.5 \times 10^{-2} \text{ms}^{-1}$
SO ₄ dry deposition velocity (\bar{v}_d)	= $0.05 \times 10^{-2} \text{ms}^{-1}$
Dry period SO ₂ to SO ₄ conversion rate (k_d)	= 1%/hr
Wet period SO ₂ to SO ₄ conversion rate (k_w)	= 1%/hr
SO ₂ wet removal rate (j)	= $3 \times 10^{-5} \text{s}^{-1}$
SO ₄ wet removal rate (\bar{j})	= $1 \times 10^{-4} \text{s}^{-1}$

2. Meteorological parameters

Average mixed layer height (z_i)	= 1000 m
Advecting wind speed (u)	= 10 ms^{-1}
Dispersion velocities (σ_u, σ_v)	= 10 ms^{-1} , 6 ms^{-1}
Lagrangian dry period duration (τ_d)	= 46 hr
Lagrangian wet period duration (τ_w)	= 7 hr
Fractional dry period at source (f_d)	= 0.9
Fractional wet period at source (f_w)	= 0.1
Emission ratio at source QSO ₂ /QSO ₄	= 0.98/0.02

Table 2

Station No.	Receptor Name	OBS	PRED	Wet sulfur deposition
				OBS/PRED
(gm ⁻² yr ⁻¹)				
1	Kingston, Ont.	1.26	0.93	1.35
2	Moosonee, Ont.	0.58	0.33	1.76
3	Mount Forest, Ont.	2.32	0.96	2.42
4	Peterborough, Ont.	1.81	0.94	1.93
5	Pickel Lake, Ont.	0.39	0.28	1.39
6	Simcoe, Ont.	2.34	1.49	1.57
7	Wawa, Ont.	0.91	0.52	1.75
8	Windsor, Ont.	2.98	2.00	1.49
9	Chibougama, Que.	1.06	0.42	2.52
10	Maniwaki, Que.	0.71	0.75	0.95
11	Montreal, Que.	2.35	0.88	2.67
12	Merrimach Cnty, N.Y.	0.91	0.93	0.98
13	Albany Cnty, N.Y.	1.20	1.21	0.99
14	Allengany Cnty, N.Y.	2.20	1.58	1.39
15	Dutchess Cnty, N.Y.	1.20	1.48	0.81
16	Essex Cnty, N.Y.	0.84	0.84	1.00
17	Oneida Cnty, N.Y.	1.70	1.08	1.57
18	Onondaga Cnty, N.Y.	0.79	1.19	0.66
19	Ontario Cnty, N.Y.	1.20	1.34	0.90
20	St. Law. Cnty, N.Y.	1.00	0.89	1.12
21	Oak Ridge, Tenn.	1.30	1.04	1.25
22	Charlottesville, Vir.	0.91	1.31	0.69
23	Tucker Cnty, W.V.	2.00	1.94	1.03
24	Washington, D.C.	1.00	1.83	0.55
25	Lewistown, Penn.	0.98	2.21	0.44
26	Paducah, Kentucky	0.57	1.29	0.44

LINEAR ANALYSIS: OBSERVED DEPOSITION = a + b *PREDICTED DESPOSITION

Receptor Location	r ²	a(gm ² /yr)	b	Receptor Excluded
Canada	0.76	0.24	1.49	
Canada	0.84	0.16	1.48	11
U.S.	0.09	0.73	0.34	
U.S.	0.47	0.05	0.98	24, 25, 26
All PT	0.19	0.67	0.58	
All PT	0.51	0.24	1.04	11, 24, 25, 26
All PT Cdn Obs Reduced 30%	0.70	0.12	0.97	11, 24, 25, 26

Table 3

Model Emission Inventory for the Sudbury Region
(10^3 tonnes SO_2 /year)

Scenario	Details of Emissions	Total SO_2 Emission
'Base Case'	INCO (1977)	1137
	Falconbridge	200
	Area and small	20
	point sources	1357
Shut-down/ Strike Period	INCO (mean 78-79)	487
	Falconbridge	
	(mean 78-79)	102
	Area and small pts	20
		609
INCO, Aug. 1980 Control Order	INCO Maximum Limit	
	Aug. 28, 1980	830
	(2500 short tons/day	
	Falconbridge Limit	154
	(465 short tons/day)	
	Area and small pts	20
		1004
INCO, 1983 Control Order	INCO Maximum Limit	
	June 1, 1983	647
	(1950 short tons/day)	
	Falconbridge Limit	154
	(465 Short tons/day	
	Area and small pts	20
		821

Note: When limits are original given in short tons the metric equivalents are round to nearest 10^3 tonnes.

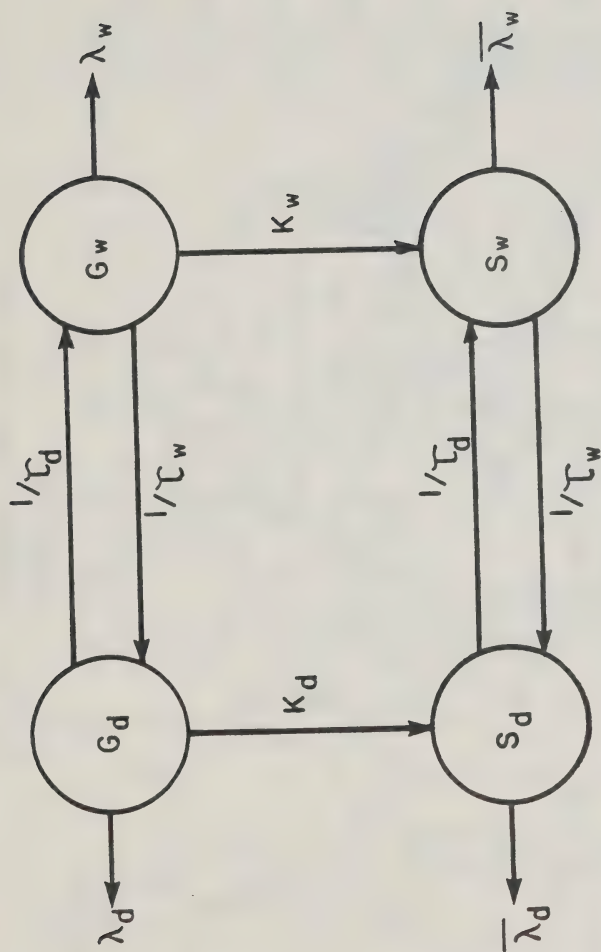
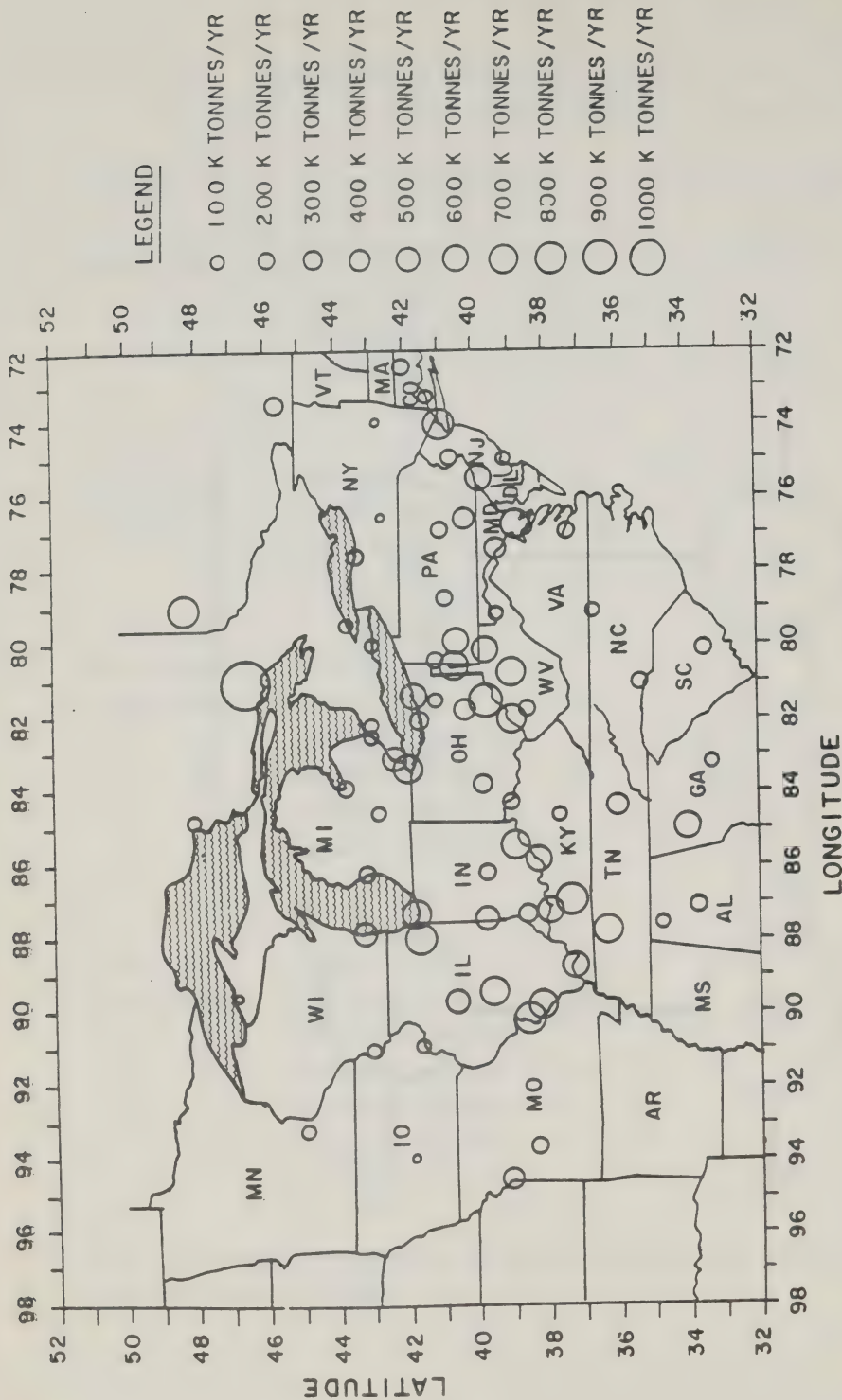


Figure 1. Schematic diagram of the scavenging model.



LONGITUDE

SOURCES OFF THE MAP

EMISS	SOURCE NAME	LAT	LONG	EMISS	SOURCE NAME	LAT	LONG
O	PORTLAND - AUGUSTA	43.4	71.0	O	FLIN FLON MAN	54.9	101.0
O	BOSTON - WORCESTER	40.3	71.3	O	MONCTON N.B.	45.5	66.0
O	NEWPORT-FALL RIVER	41.7	71.1	O	NOVA SCOTIA	45.0	62.8

Figure 2. Distribution and relative magnitude of model SO₂ emission inventory.

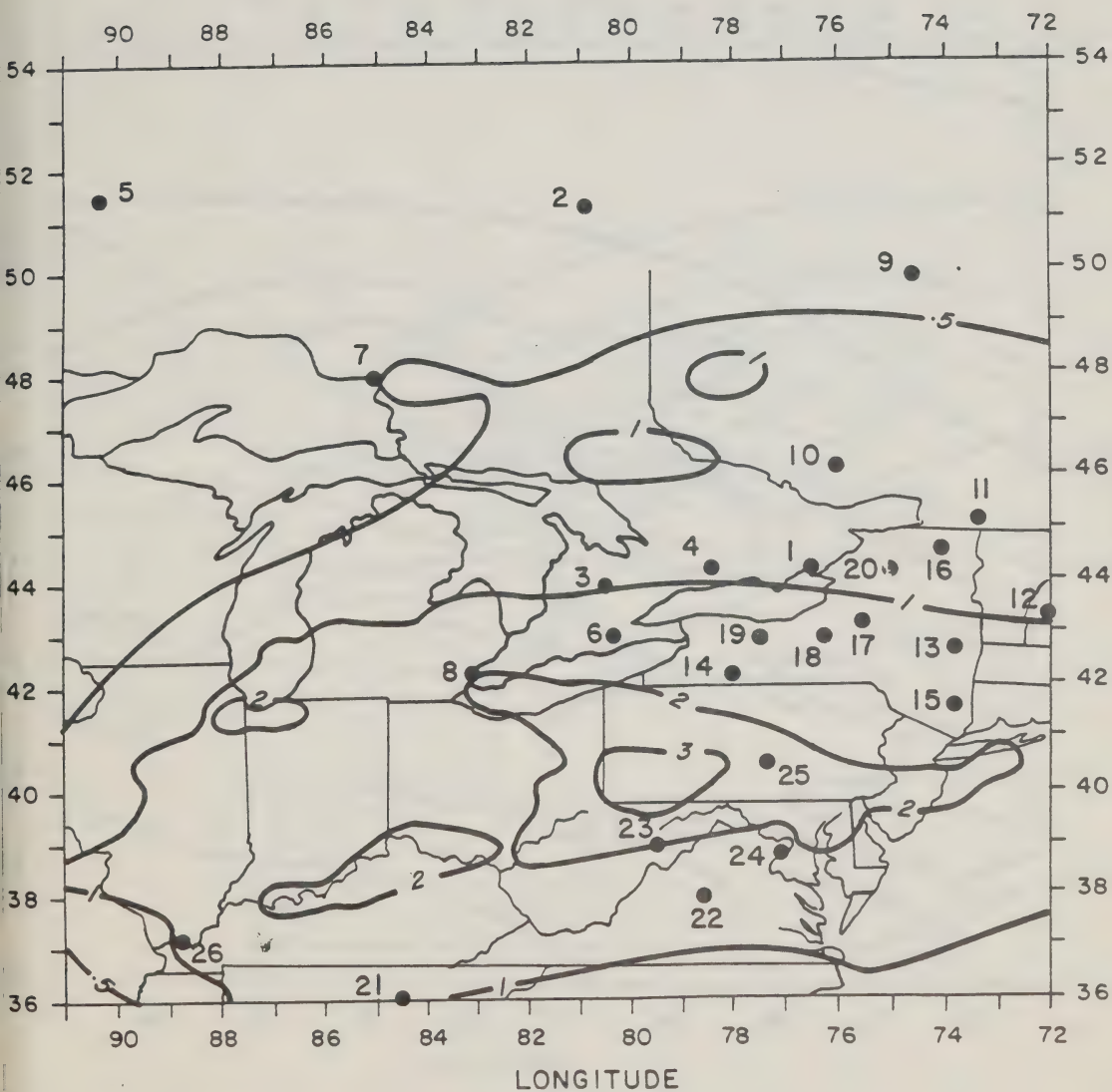


Figure 3. Model predictions of annual wet deposition of sulfur in $\text{gm/m}^2/\text{year}$. Stars in figure correspond to monitors in the CANSAP and U.S. networks. Numbers next to stars are station codes referred to in Table 2.

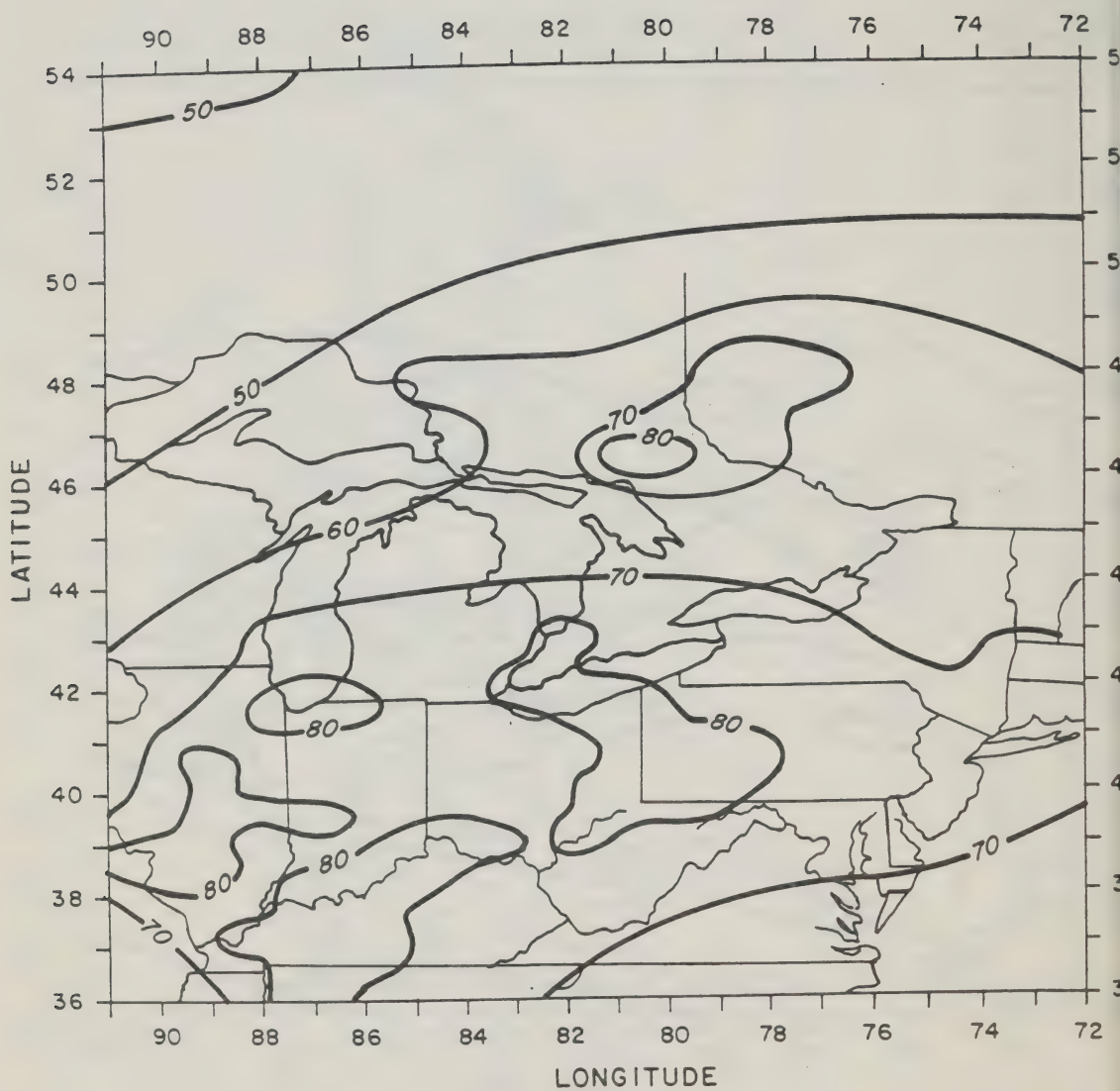


Figure 4. Relative contribution of SO_2 to the total wet deposition of sulfur.

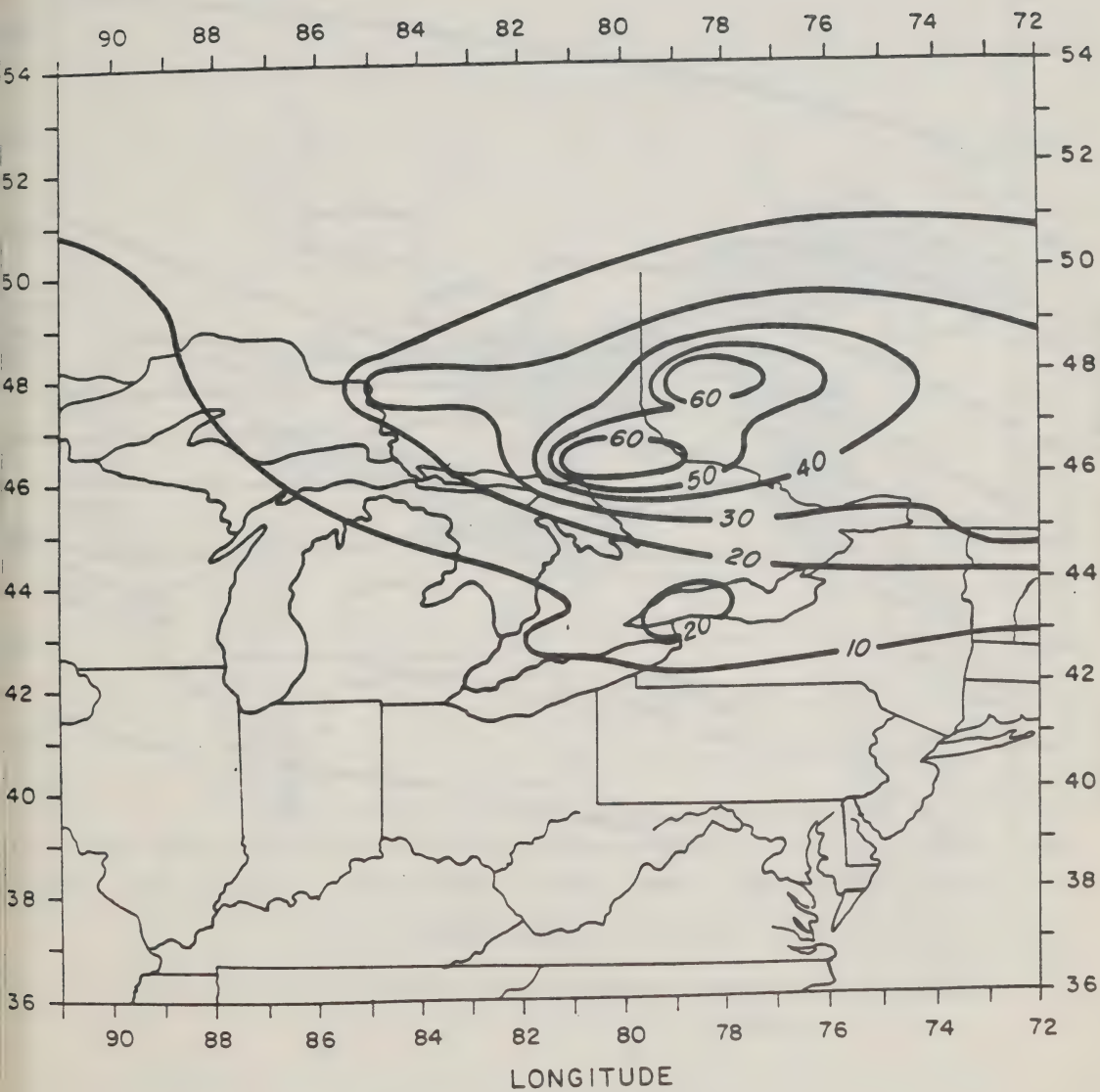


Figure 5. Percentage contribution of Canadian SO_x sources to the wet deposition of sulfur.

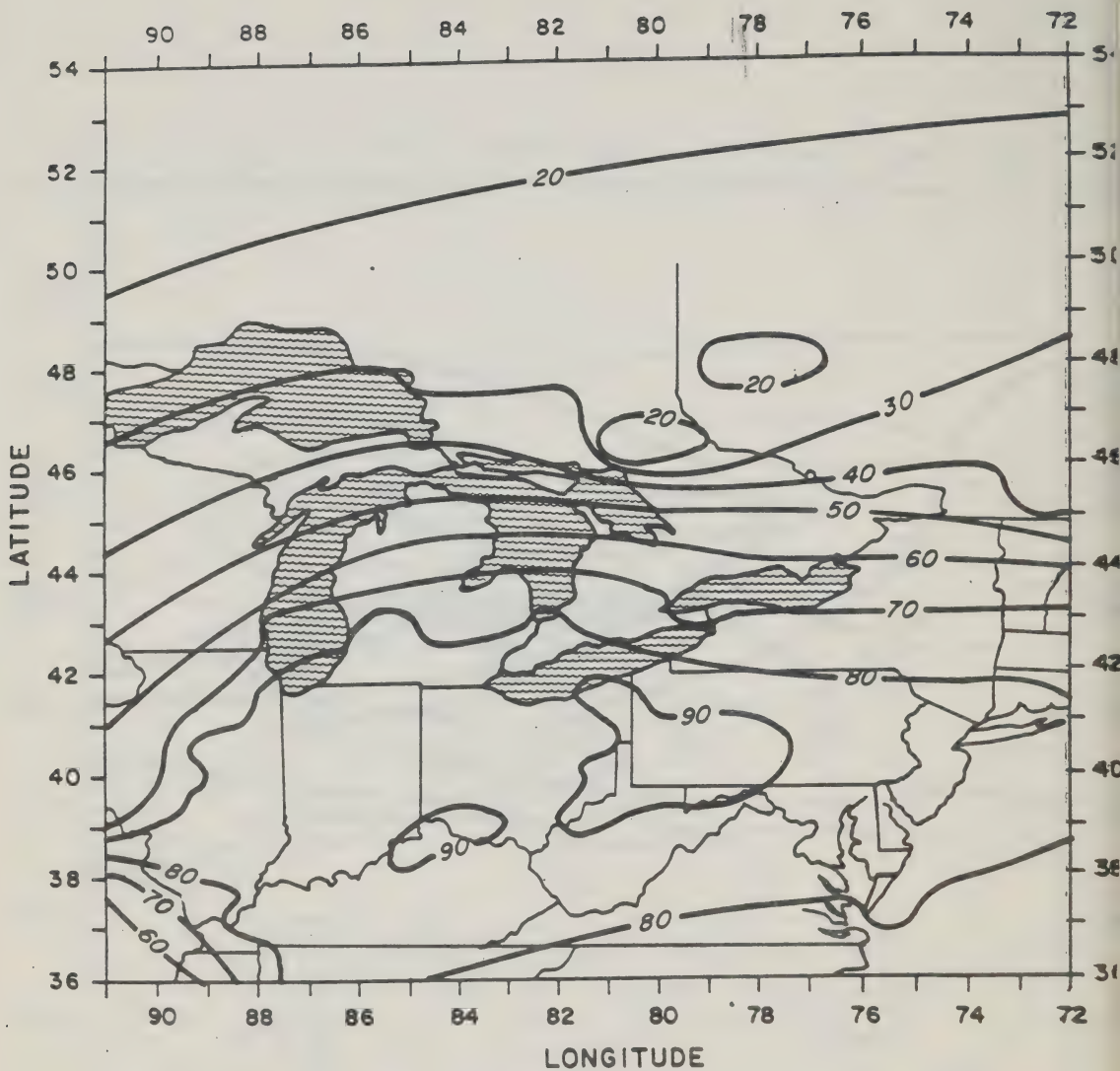


Figure 6. Percentage contribution of U.S. SO_x sources to the wet deposition of sulfur.

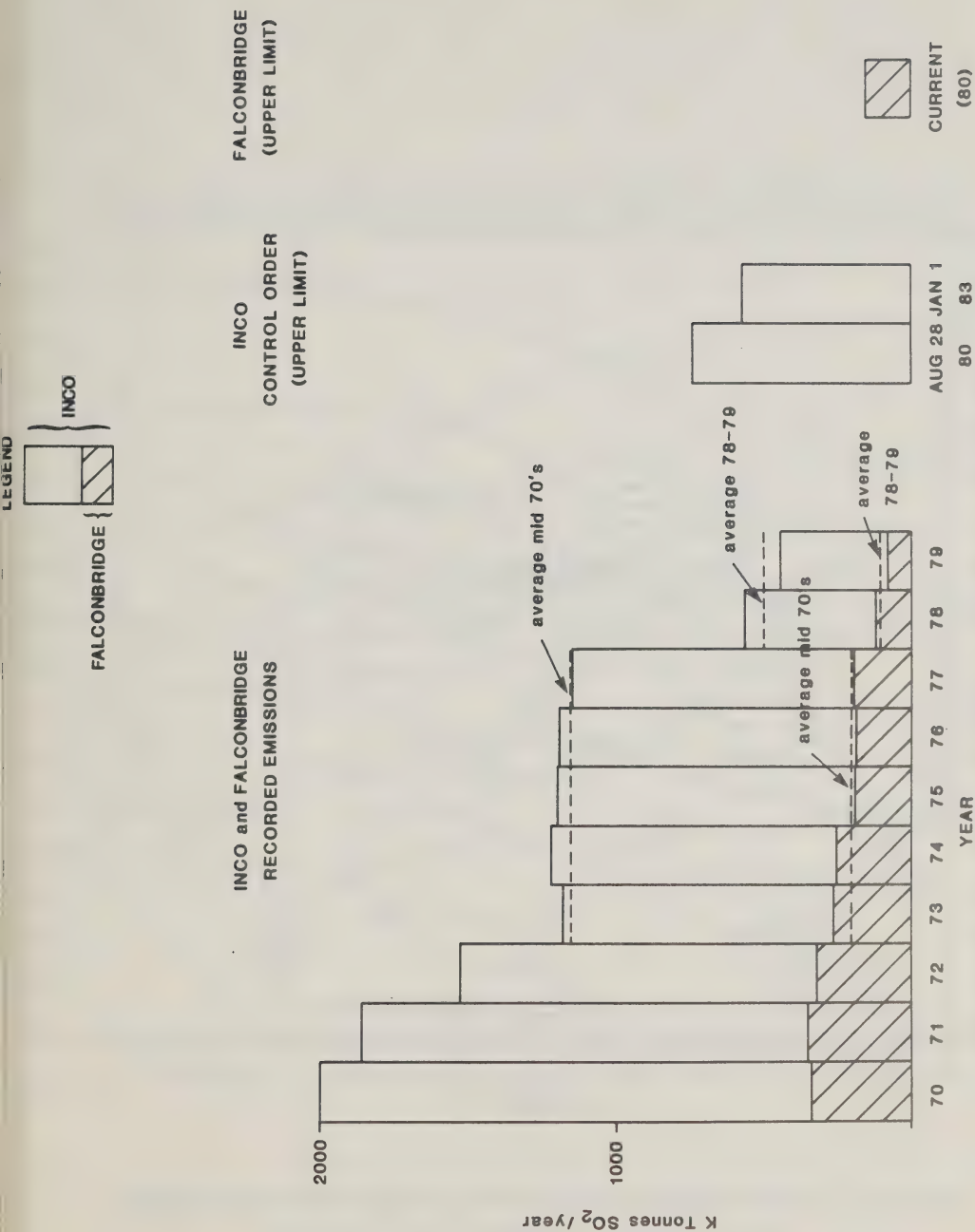


Figure 7. Sulfur dioxide emission records and current maximum emission limits for the major emitters in the Sudbry area.

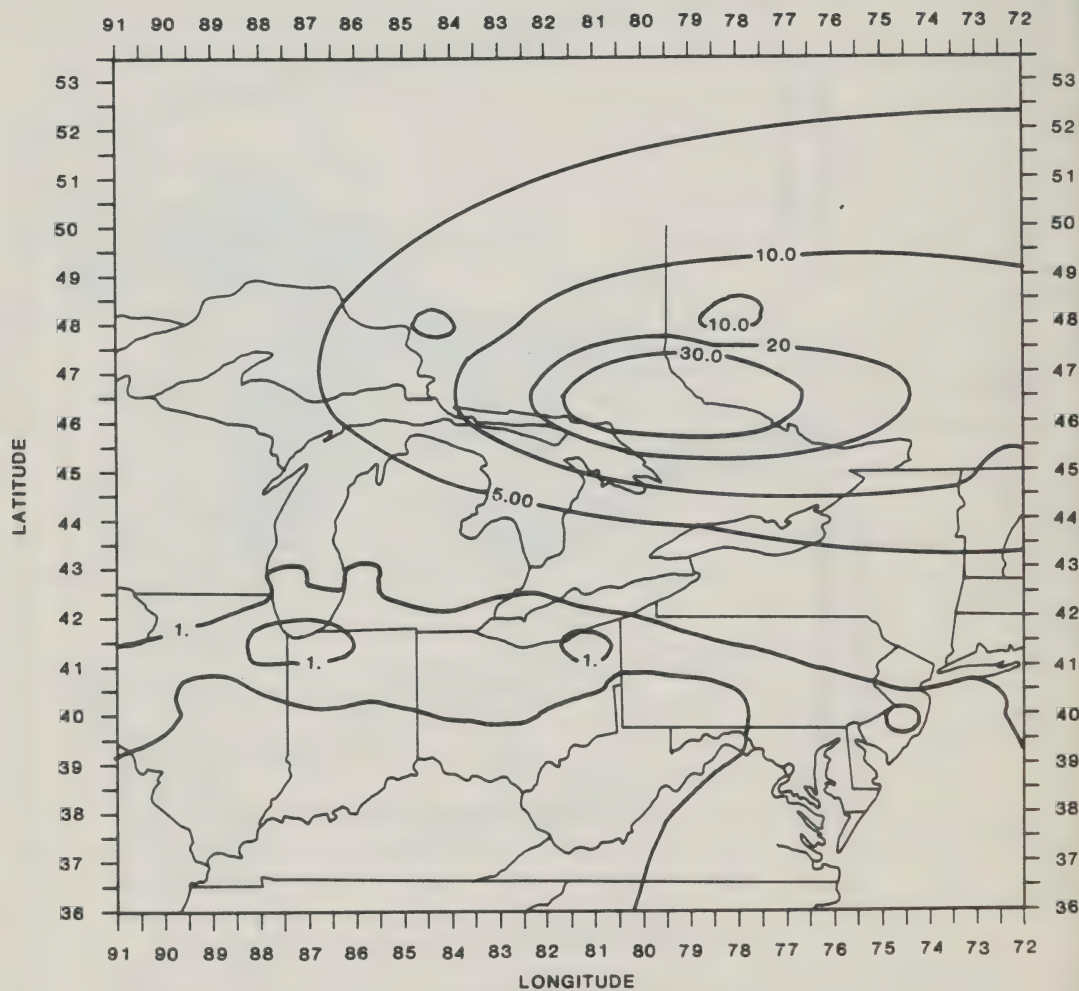


Figure 8. Percentage contribution of SO_x sources in the Sudbury region to the total wet deposition of sulfur.

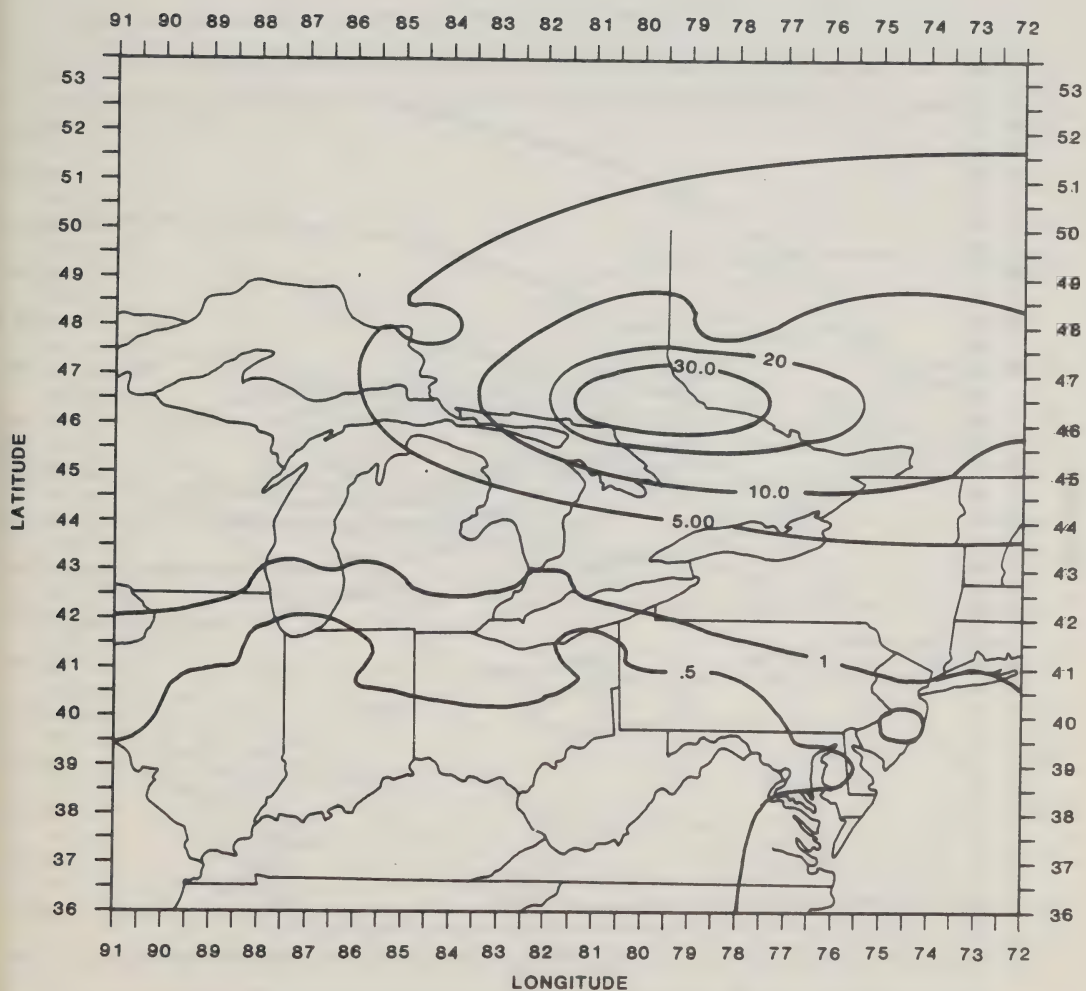


Figure 9a. Percentage contribution of SO_x emissions from INCO to the total wet deposition of sulfur.

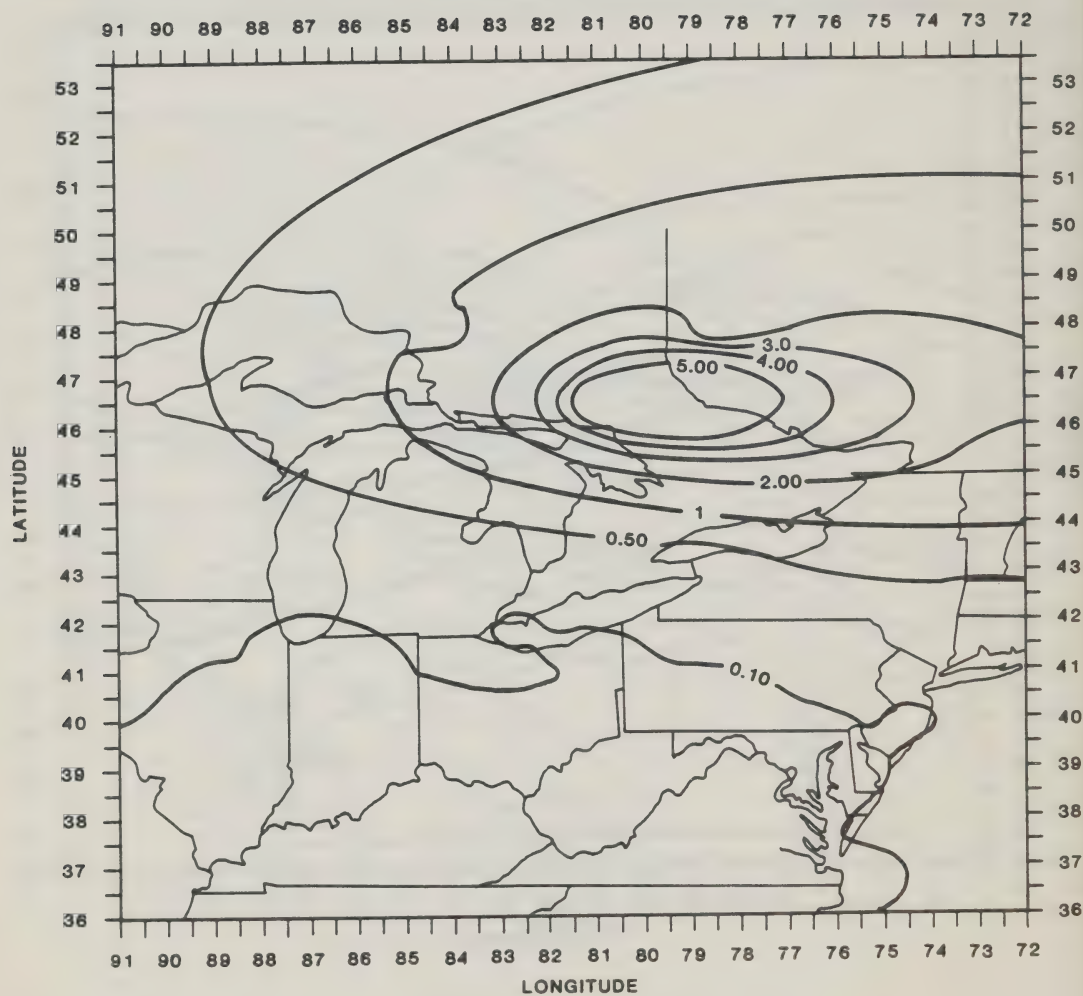


Figure 9b. Percentage contribution of SO_x emissions of SO_x emissions from Falconbridge to the total wet deposition of sulfur.

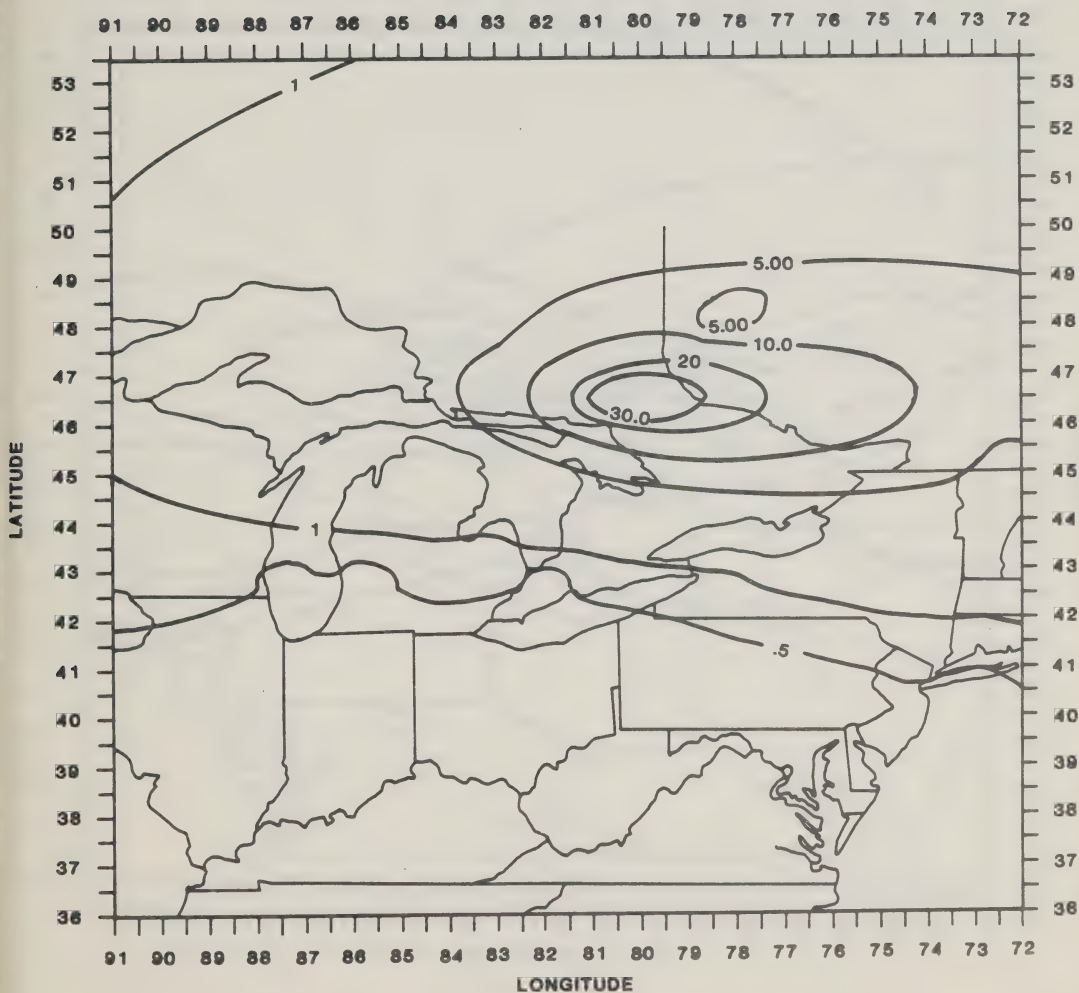


Figure 10. Percentage contribution of SO_x sources in the Sudbury region to the total wet deposition of sulfur during the strike/shut-down years 1978-79.

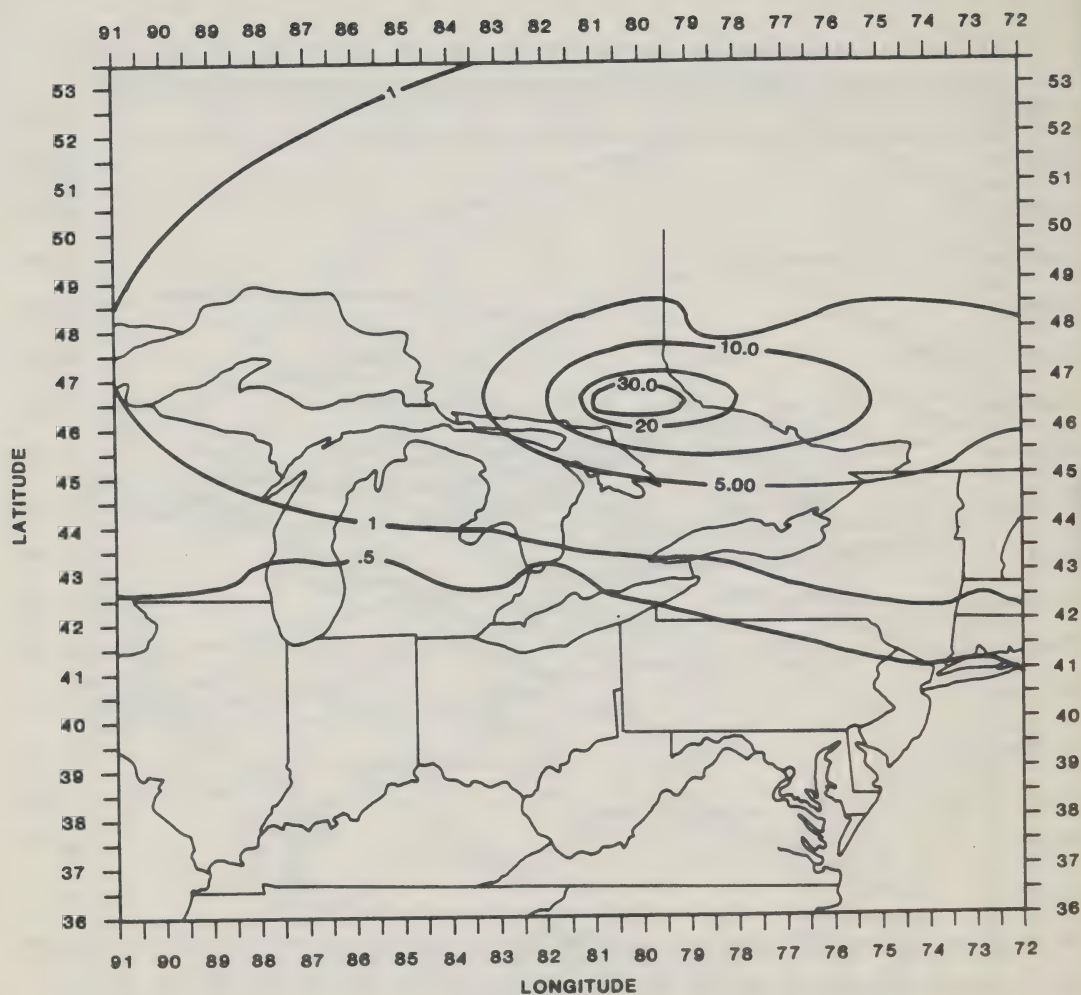


Figure 11a. Percentage contribution of SO_x emissions from INCO to the total wet deposition of sulfur during 1978-79.

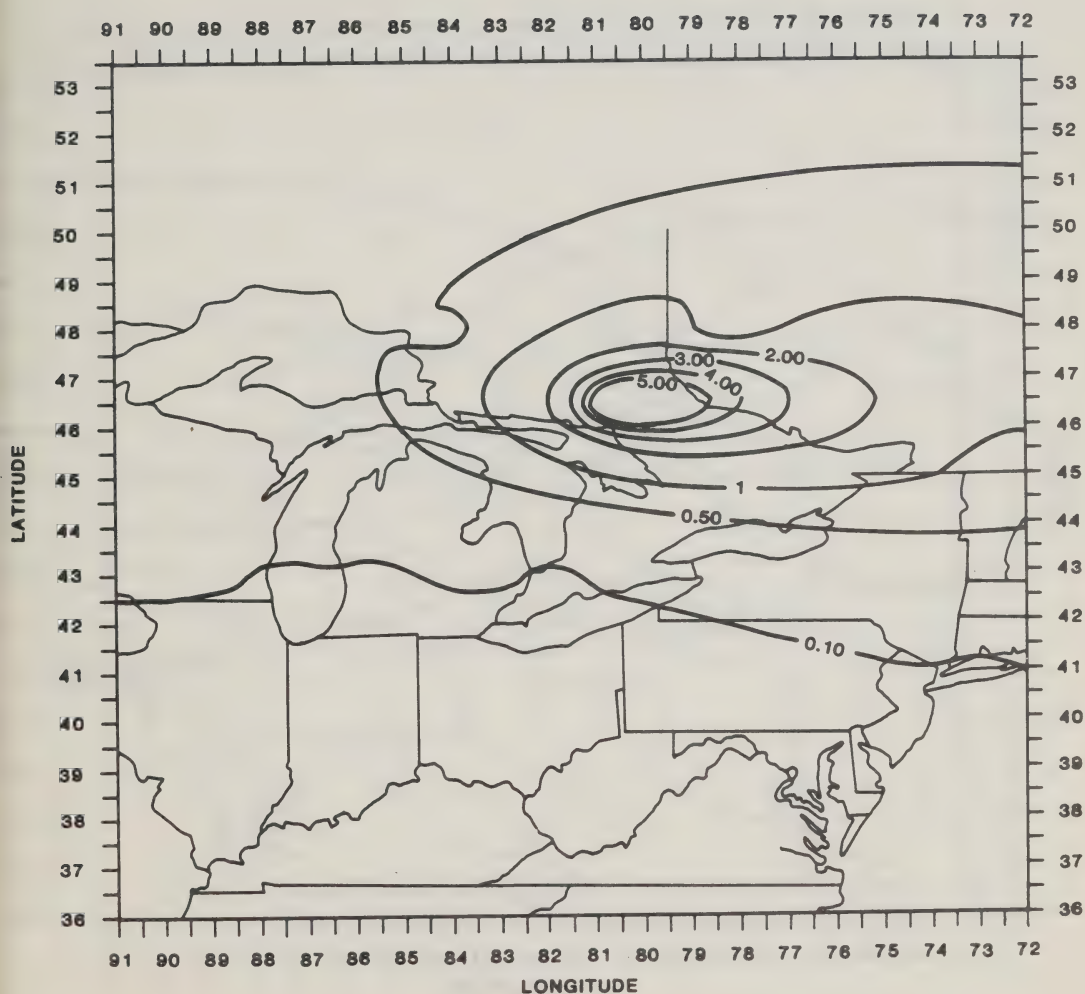


Figure 11b. Percentage contribution of SO_x emissions from Falconbridge to the total wet deposition of sulfur during 1978-79.

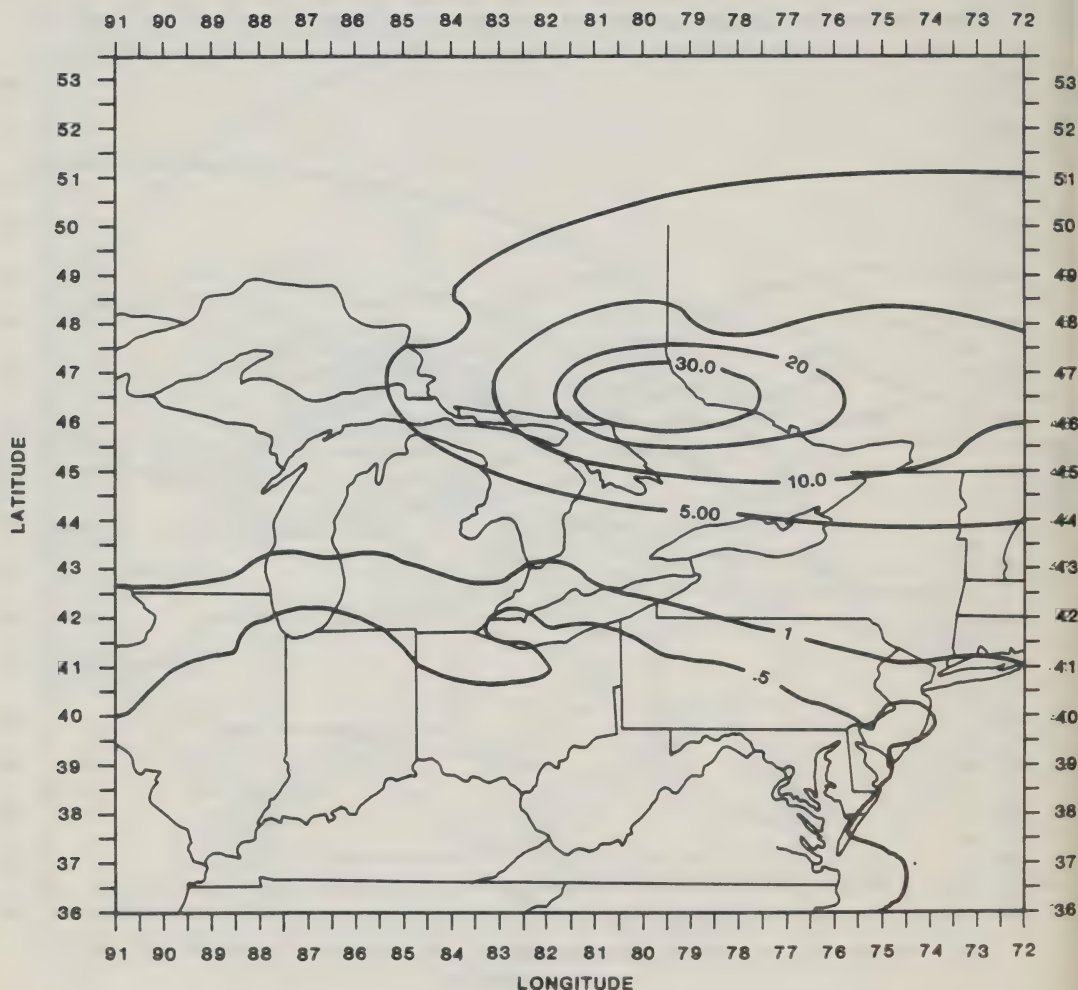


Figure 12. Estimated percentage contribution of SO_x sources in the Sudbury region to the wet deposition of sulfur assuming INCO's emissions are the maximum currently (Dec. 1980) allowable under the August 28, 1980 Control Order and Falconbridge's emissions are the maximum currently allowable.

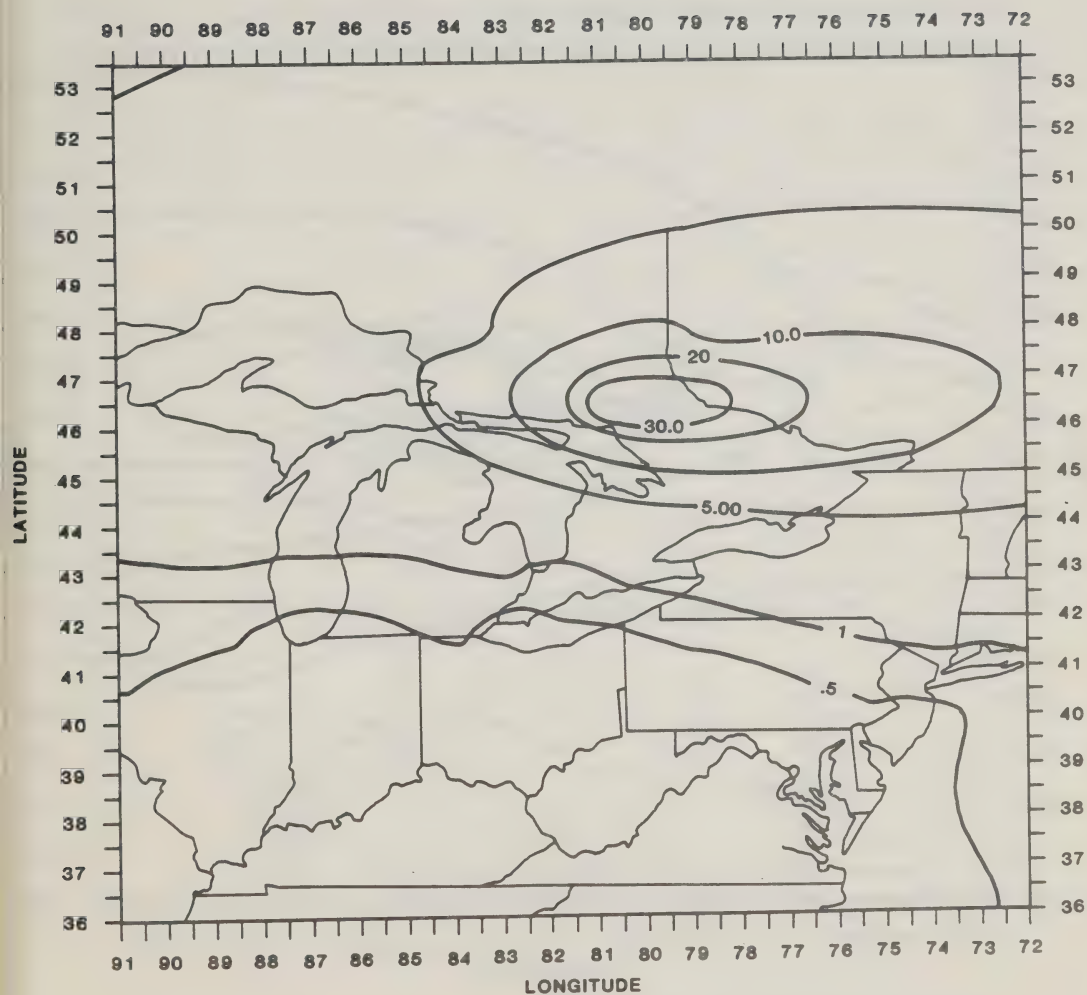


Figure 13a. Estimated percentage contribution of SO_x emissions from INCO to the wet deposition of sulfur assuming INCO's emissions are the maximum currently allowable under the August 28, 1980 Control Order.

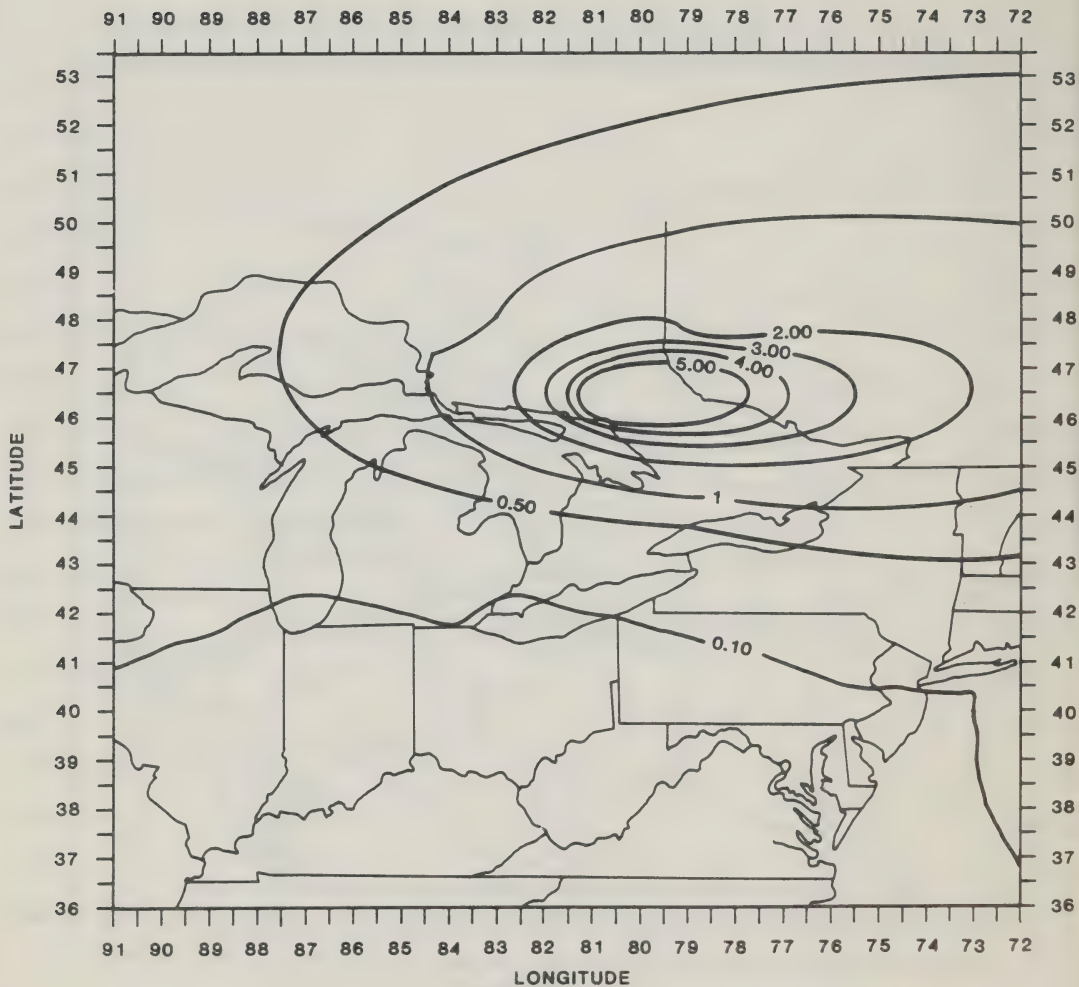


Figure 13b. Estimated percentage contribution of SO_x emissions from Falconbridge to the wet deposition of sulfur assuming Falconbridge's emissions are the maximum allowable under the current limits.

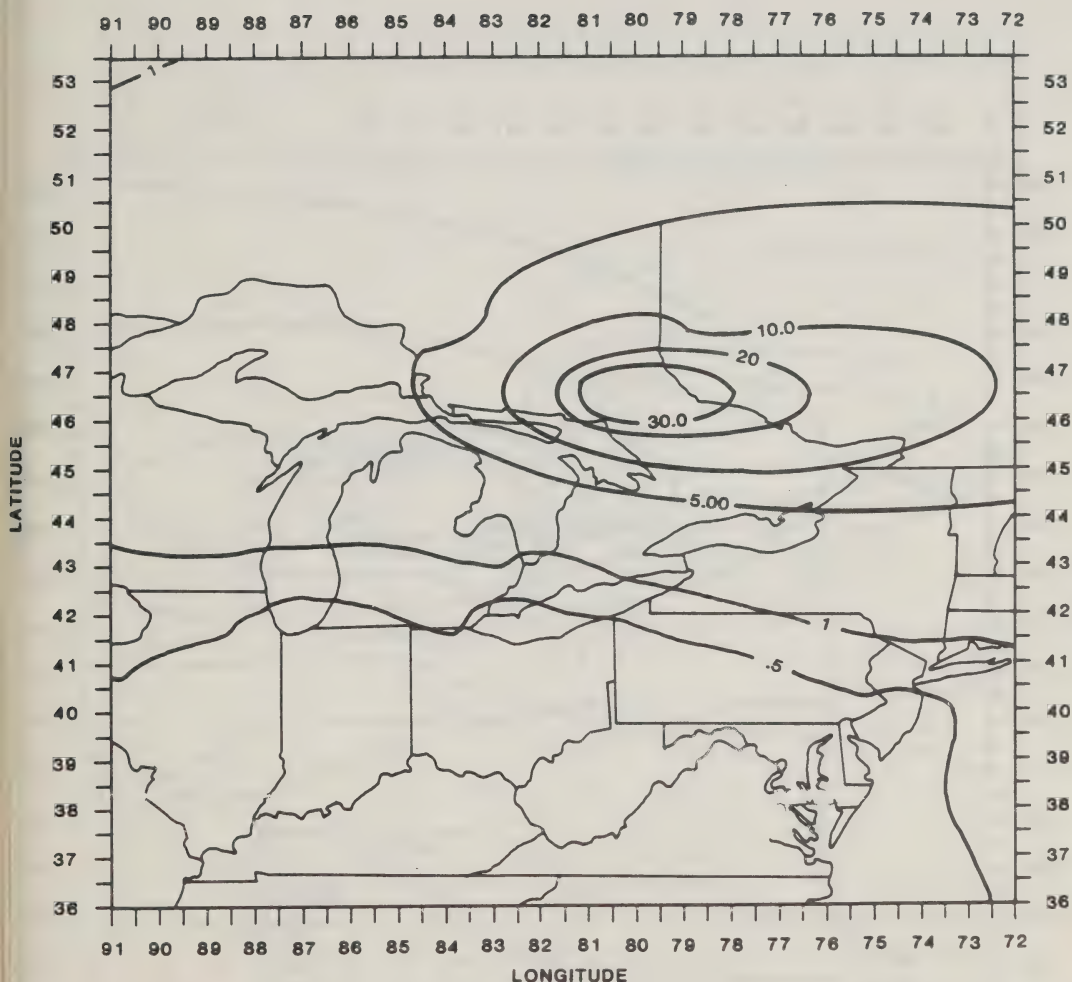


Figure 14.

Estimated percentage contribution of SO_x sources in the Sudbury region to the wet deposition of sulfur assuming Falconbridge's emissions are the maximum currently allowable and INCO's emissions are the maximum allowable after December 31, 1982, under the August 28, 1980 Control Order.

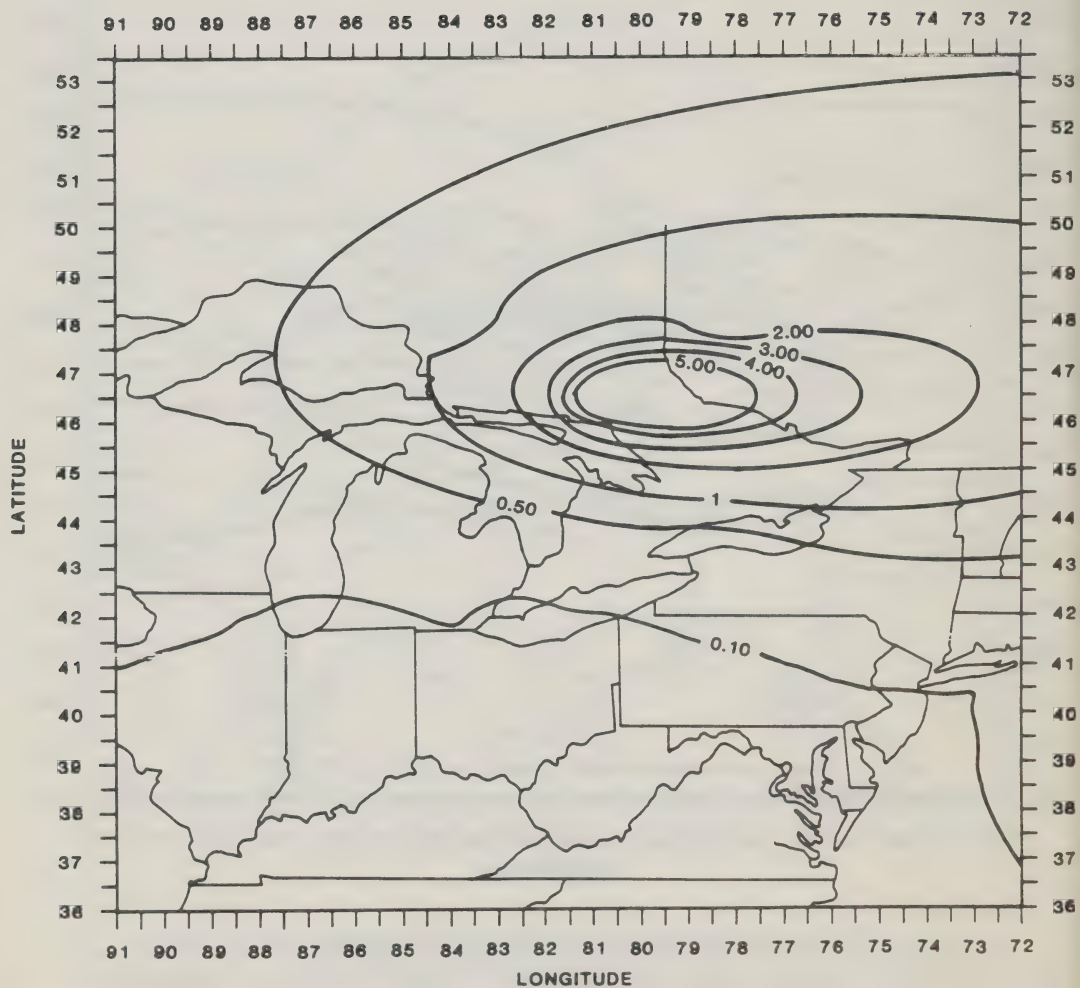


Figure 15a. Estimated percentage contribution of SO_x emissions from INCO to the wet deposition of sulfur assuming the same emission limits as in Figure 14 for Falconbridge and INCO.

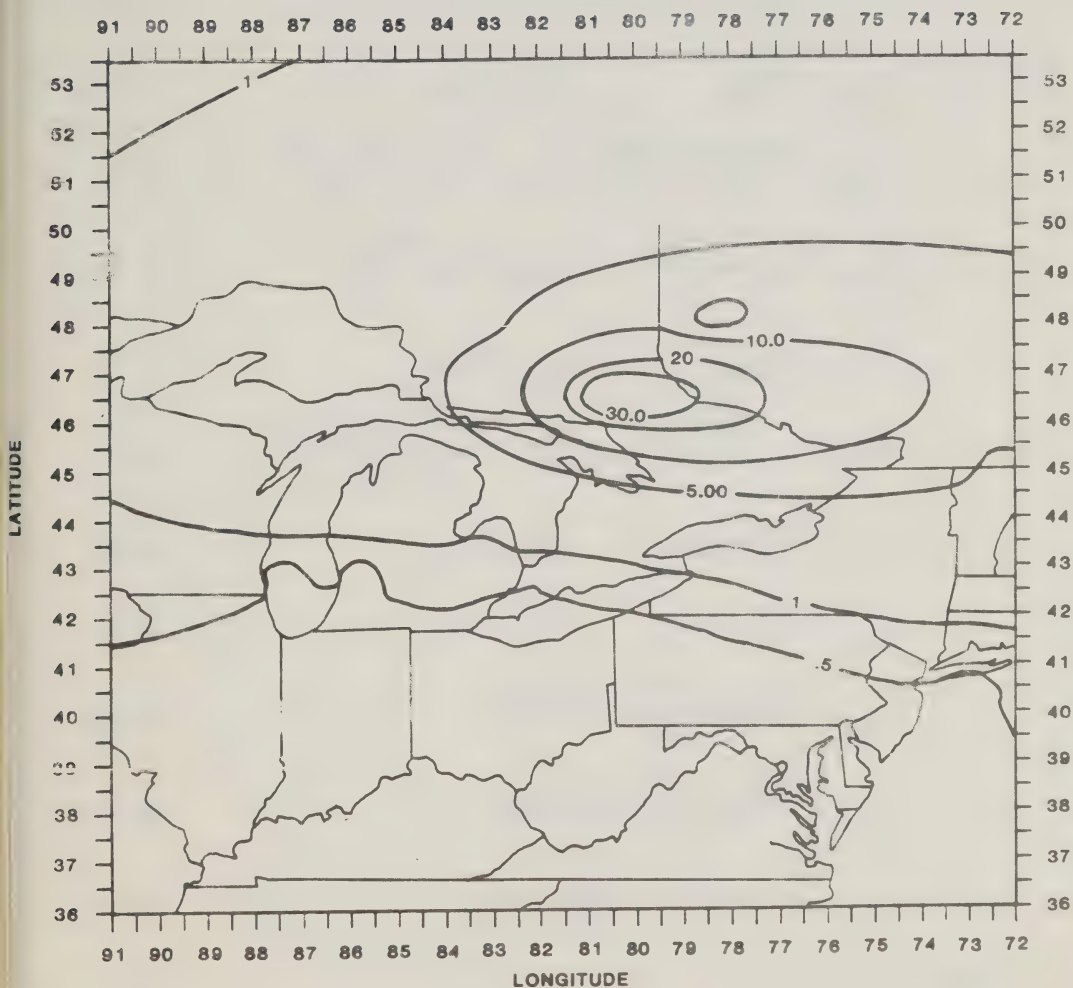


Figure 15b. Estimated percentage contribution of SO_x emissions from Falconbridge to the wet deposition of sulfur assuming the same emission limits as in Figure 14 for Falconbridge and INCO.

The constants in equations (4a) and (4b) are given by:

$$\alpha_{1,2} = -\frac{(\bar{\ell}_d + \bar{\ell}_w)}{2} \left[1 \pm \left\{ 1 - \frac{4(\bar{\ell}_d \bar{\ell}_w - g_d g_w)}{(\bar{\ell}_d + \bar{\ell}_w)^2} \right\}^{\frac{1}{2}} \right] \quad (A.1)$$

where

$$\ell_d = k_d + \lambda_d + 1/\tau_d ; \ell_w = k_w + \lambda_w + 1/\tau_w \quad (A.2)$$

$$g_d = 1/\tau_w ; g_w = 1/\tau_d \quad (A.3)$$

$$A_{d1} = \frac{p_d(\alpha_2 + \ell_d) - p_w g_d}{(\alpha_2 - \alpha_1)} ; A_{d2} = \frac{p_w g_d - p_d(\alpha_1 + \ell_d)}{(\alpha_2 - \alpha_1)} \quad (A.4)$$

$$A_{w1} = A_{d1} \frac{(\alpha_1 + \ell_d)}{g_d} ; A_{w2} = A_{d2} \frac{(\alpha_2 + \ell_d)}{g_d} \quad (A.5)$$

$$p_d = f_d Q_{SO_2} ; p_w = f_w Q_{SO_2} \quad (A.6)$$

$$\gamma_{1,2} = -\frac{(\bar{\ell}_d + \bar{\ell}_w)}{2} \left[1 \pm \left\{ 1 - \frac{4(\bar{\ell}_d \bar{\ell}_w - \bar{g}_d \bar{g}_w)}{(\bar{\ell}_d + \bar{\ell}_w)^2} \right\}^{\frac{1}{2}} \right] \quad (A.7)$$

$$\bar{\ell}_d = \bar{\lambda}_d + 1/\tau_d ; \bar{g}_d = 1/\tau_w \quad (A.8)$$

$$\bar{\ell}_w = \bar{\lambda}_w + 1/\tau_w ; \bar{g}_w = 1/\tau_d \quad (A.9)$$

$$\beta_{di} = \frac{\bar{k}_d A_{di}(\alpha_i + \bar{\ell}_w) + \bar{g}_d A_{wi} k_w}{\epsilon_i} \quad (A.10)$$

$$\beta_{wi} = \frac{\bar{k}_w A_{wi}(\alpha_i + \bar{\ell}_d) + \bar{g}_w A_{di} k_d}{\epsilon_i} \quad (A.11)$$

$$\epsilon_i = (\alpha_i + \bar{\ell}_d)(\alpha_i + \bar{\ell}_w) - \bar{g}_w \bar{g}_d \quad (A.12)$$

and

$$B_{d1} = \frac{v_d(\gamma_2 + \bar{\ell}_d) - v_w \bar{g}_d}{(\gamma_2 - \gamma_1)} ; B_{d2} = \frac{v_d \bar{g}_d - v_w(\gamma_1 + \bar{\ell}_d)}{(\gamma_2 - \gamma_1)} \quad (A.13)$$

$$B_{w1} = \frac{B_{d1}(\gamma_1 + \bar{\ell}_d)}{\bar{g}_d} ; B_{w2} = \frac{B_{d2}(\gamma_2 + \bar{\ell}_d)}{\bar{g}_d} \quad (A.14)$$

where

$$v_d = - \sum_{i=1}^2 \beta_{di} + f_d^Q SO_4 \quad ; \quad v_w = - \sum_{i=1}^2 \beta_{wi} + f_w^Q SO_4 \quad (A.15)$$

$$\bar{k}_d = \frac{3}{2} k_d \quad ; \quad \bar{k}_w = \frac{3}{2} k_w \quad (A.16)$$

APPENDIX 13

COMMENTS ON THE TESTIMONY

OF

DR. VOLKER MOHNEN

BEFORE THE U.S. EPA HEARINGS ON

INTERSTATE POLLUTION ABATEMENT

All of the scientific and technical data and information which New York, Pennsylvania and Ontario have presented thus far substantiates the thesis that emissions (and their secondary products) from power plants in the midwestern States are being deposited in New York, Pennsylvania and Ontario in amounts which cause exceedances of the NAAQS or ambient air quality standards or criteria. However the testimony of Dr. Volker Mohnen, on behalf of the "Utilities", presents an opinion which is considerably different from that stated above and Ontario feels that special comments are required to refute this evidence.

From the outset, it is realized that Dr. Mohnen is the Director of a highly respected Atmospheric Sciences Research Centre in the United States and he is personally well-known internationally. As a result of his position and reputation, his testimony would be considered highly by the Hearing Board. There are however a number of significant areas where New York and Pennsylvania, supported by Ontario, would be in disagreement with Dr. Mohnen's testimony.

There are certain basic facts in our current understanding of the emissions and fate of atmospheric sulphur compounds which are accepted by the scientific community both in North America and Europe, and probably would not be denied by Dr. Mohnen himself. These are:

1. The anthropogenic contribution dominates the sulphur emissions in E. North America, being about 10 times greater than natural emissions. Of the anthropogenic emissions, a very large proportion (almost one-half) are concentrated in the Midwestern states, and are largely due to utilities (almost 80% of the total).
- 2 The residence time of sulphur compounds in the atmosphere is typically one to five days, with sulphur dioxide being converted at rates of up to a few percent per hour to sulphates. Thus, long range transport and chemical transformation downwind of the source areas occurs throughout the year.

These facts, together with the knowledge that the prevailing wind regime over much of E. North America is westerly, lead to the strong expectation that utility

emissions in the Midwestern states are impacting on New York and Pennsylvania and Ontario, as far as sulphur dioxide and sulphates are concerned.

In his submission, Dr. Mohnen tries, on the contrary, to prove that "...there is no valid evidence that even a substantial reduction of SO₂ emissions (from the Midwest) would have any measurable impact in reducing sulphate levels, or TSP violations, in New York or Pennsylvania."

Dr. Mohnen points out that some of the studies cited by New York and Pennsylvania were not sufficiently refined to relate high sulphate concentrations to SO₂ emissions from Midwestern sources, and did not include adequate consideration of a number of significant variables such as air mass stagnation, ozone and humidity levels, mixing heights, and particulate concentrations. In fact, he contends that more recent and sophisticated work has illustrated the dominance of meteorological and other air chemical parameters over upwind SO₂ emissions in explaining ambient sulphate. He emphatically repeats several times in his presentation that there is no "linear relationship" between SO₂ emissions in the Midwest and ambient sulphate levels in the Northeast. Dr. Mohnen's testimony therefore is that sulphate levels depend not only on the sulphur emissions but on the meteorological and chemical characteristics of the atmosphere

and that an increase or decrease in emissions may not result in a corresponding increase or decrease in sulphates measured downwind. However, we wish to point out that during any given time period, these characteristics are fixed and the sulphate levels measured downwind of sulphur emitting sources will be directly related to the rate of the sulphur compounds emitted to the atmosphere during that period.

Dr. Mohnen admitted, that there is a relationship between SO_2 and sulphates saying "you must have SO_2 to make sulfates" and follows this with the dependence upon atmospheric chemical parameters, which we do not take issue with. He however adds that a reduction in sulphur dioxide emissions will not make sulphate levels necessarily worse or better, a matter with which we surely disagree.

Dr. Mohnen sites work by Liou et al, that showed that sulphate levels depended on regional ozone as well as meteorological factors. This is true, however, ozone is much more difficult to control than SO_2 emissions since there is a large natural component (1/4 to 1/2 of the ozone in the atmosphere). Keeping ozone levels and meteorological factors the same, sulphate levels will depend on the amount of SO_2 emitted to the atmosphere. The same is true for his critique of work by Wolff et al.

Whether the winds have transported the SO_2 and sulphates first southward and then northeastward from the mid-west is not an argument against limiting emissions.

In reference to Dr. Samson's work, there is no doubt that sulphate levels will vary due to meteorological conditions, a matter too obvious for Dr. Samson to want to state in his paper. Fluctuations will occur for any pollutant concentration downwind of sources due to meteorological condition changes. Since we cannot control the weather, the only means of limiting the pollutant levels is to limit the pollutant emissions and the major emitted pollutant forming sulphates is sulphur dioxide.

Meteorological and atmospheric chemistry processes are admittedly very important during long range transport, and such factors as wet and dry deposition, conversion to reaction products, and redistribution of emissions within the mixing layer during the diurnal cycle become relatively more important (compared to emission rates) as the distance increases between source and receptor. All current LRTAP mathematical models do in fact take meteorology, chemistry and deposition into account in one way or another. However, one certainly cannot conclude, on the basis of the evidence presented, that "...a reduction in SO_2 emissions (from the Midwestern sources) might not - and probably would not

result in a measurable reduction in sulphate levels in New York and Pennsylvania." Dr. Mohnen seems to ignore the massive upwind source of anthropogenic SO_2 emissions, and talks in terms of a rather vague reservoir of atmospheric sulphur dioxide, which is acted on by chemistry and meteorology to produce sulphates in New York. Granting the fact that chemistry and meteorology are dominant factors, one wants to ask, "Where did all the sulphur come from in the first place?".

In other words, the significance of upwind sources seems to be downgraded by ignoring certain basic facts about sulphur emissions in E. North America, prevailing wind patterns, and the atmospheric lifetime of sulphur compounds, while at the same time citing evidence rather selectively from a limited number of references, which deal primarily with event analysis (rather than long-term results). While event analysis can yield interesting and valuable information, it is also a very difficult undertaking. For example, some of the more recent and advanced analyses cited by Mohnen are not entirely in agreement with each other about which factors are important for ambient sulphates (especially the mixing height). Also, a large number of investigations into sulphate and ozone episodes and their meteorological interpretation (not considered by Dr. Mohnen) have led to an impressive body of evidence that major upwind source

areas are having a significant impact on receptor areas such as New York or Ontario. Dr. Mohnen has convincingly demonstrated that when interpreting sulphate episodes it is important to include a detailed chemical and meteorological analysis, because of the complexity of the problem. However, the references cited do not lead to the conclusion that Midwestern source emission reductions would have no effect on sulphate levels in New York or Pennsylvania. In fact we wish to repeat that since the meteorological and chemical component characteristics of the atmosphere are fixed, the sulphate concentrations will depend only on the upwind emission rates of sulphur compounds into the atmosphere.

Turning to more specific items, Dr. Mohnen has tried to demonstrate that precipitation data also show no linear relationship between emissions and wet deposition. Dr. Mohnen claims there is no gradient in the wet sulphate deposition concentration by comparing Champaign, Illinois data with Ithaca and Whiteface Mountain, New York. A very significant gradient would only occur if the winds were only blowing in a west to east direction, a fact that he should know is not true. Winds with varying frequency occur in all directions. SO_2 and sulphates will be transported into Illinois with easterly winds and into New York during southwest wind conditions.

He chose an Illinois location which was nearer to the source area being considered than the locations in New York State. There are in fact large coal burning power plants in Southern Illinois, south and southwest of the Champaign site. These are the Baldwin (outside East St. Louis), Coffeen, Kincaid and Joppa Steam power plants which in total emit approximately 640 thousand tonnes of SO_2 per annum. These sources are 120 to 300 km from Champaign. There are no large sources as near to Whiteface Mountain that could distort the data similarly. It is thus not surprising that the site showed a high % of sulphates in precipitation during events with trajectories in the directions similar to that at Whiteface Mountain.

Furthermore, the two sites are much different in nature including elevation, precipitation amounts (3 times as much at Whiteface Mountain), type of precipitation and seclusion from local sources. These differences may be as important as the fact that one is well to the east of the source area and one is supposedly west of it. If Dr. Mohnen had selected locations as far to the west of the source area as the sites, Ithaca and Whiteface Mountain are to the east, he would have found the gradient that he said does not exist.

The highest deposition will of course be over the source area since the average wind speed, will only transport pollution a distance of some 200 miles in 24 hours. Deposition does take place during this transport but a large proportion is ventilated out of the area as indicated by the measured levels in New York, Pennsylvania and Ontario, as well as by the visual evidence from satellite pictures and aircraft observations.

Much of Mohnen's analysis is based on recent MAP3S and NADP network data. He claims that, when allowance is made for the fact that the amount of sulphates and nitrates deposited depends strongly on the total precipitation amount (a well-known fact), the data show the existence of a regional "superbowl" - i.e., a synoptic - scale airshed that results in acidic material being rather evenly deposited in all directions over a very large region, with no major source area influences being apparent.

It should be pointed out that Mohnen's procedure of "normalizing" the deposition data by total precipitation amount is apparently simply equivalent to calculating the average concentration during the period in question. If his conclusions are compared with the results of other workers, they are found to be questionable. For example,

Pack (Science, 208, 1142 (1980)) has done a similar analysis on regional concentrations, using approximately one year's data from MAP3S (August 1978 - June 1979), but supplemented with data from the SURE network. Pack's more extensive database shows fairly clearly the influence of the major sources in the Midwest on precipitation sulphate and nitrate concentrations. Pack concludes that "...There is a definite north-south gradient, with the SO₄ concentrations at the southern edge of the data lower by 30 to 50 percent than the maximum concentrations...." Similarly, a recently published map of SO₄ concentrations from the NADP and CANSAP networks during the period March 1979 - March 1980 (Project NC-141-NADP Annual Report, January 1 - December 31, 1980) shows the influence of major source areas on sulphates in precipitation.

It is agreed that the wet sulphate deposition will depend on the amount of rainfall. However, where there is lesser rainfall, more of the deposition will be dry. The total deposition will depend on the sulphur emitted to the atmosphere, a fact that Dr. Mohnen chose to ignore, in that it more or less defeats his purpose.

Dr. Mohnen then goes to European data to further support his thesis, citing particularly the work of Granat, who did a detailed analysis of precipitation data

from the European atmospheric chemistry network, and found that while at some stations sulfate levels in precipitation approximately followed sulphur dioxide emission trends, at other stations they did not. Mohnen presents Granat's analysis as leading to the conclusion "...that increased sulphur emissions, even by as much as 50%, are not synonymous with increased sulphur wet deposition in a given network".

Although the above statement is consistent with Granat's results, it is hardly fair to present it as the "bottom line" of his work. Granat himself discussed his observations on emissions and deposition in the light of meteorology, network design, and other factors, such as changing emissions heights. Based on his analysis, he speculated that "...increasing amounts of sulphur have been deposited in areas not covered by the network, probably eastward of major sulphur emission areas, due to the general circulation over the area". From Granat's analysis one can hardly jump to the conclusion, as does Mohnen, that "...an area of New York - the Adirondacks, for example - would not necessarily experience any measurable change in acidic deposition as a result of a change in overall SO₂ emissions for the entire Midwest". Granat's suggestion - that the European observations are due to network design rather than an insensitivity of deposition to emission rates, seems to have been appreciated by Mohnen even though he downplays it,

because he talks of insensitivity of deposition to emissions "in a given network", and no measurable change in deposition "in the existing Northeastern United States Network".

Again, while Mohnen has demonstrated the complexity of wet deposition of sulfates, the evidence he has presented does not prove that the Midwest is having an insignificant effect on wet deposition in New York.

Current models generally take a simplified approach to atmospheric chemistry, transport and deposition, and this can be particularly unsuitable for event analysis. However for long-term modelling, e.g., Ontario's statistical model, one can question some of the "musts" that Mohnen has listed, in his submission, as model requirements, but this question will only be resolved when the outputs of future, complex and simplified models are compared with each other, as well as with experimental data. It is not always necessary to know all the factors in every detail to develop a model. Thus modelling should be viewed from a holistic approach. Whereas each module in the model must be built upon good and reasonably accurate hypotheses, the true test of the model lies in how well its end results compare with data. If reasonably simplifying assumptions at the component modules level serve to obtain a good comparison of model

output with measured data, then the model may be assumed to be valid and good. The Ontario long range statistical model has been validated utilizing both Canadian and U.S. sulphate deposition data. The model predicts an ensemble average so that any given observation over a finite averaging period may not agree with the model predictions. However over the total averaging period the predicted results are in reasonable agreement with the levels of measured deposited materials.

Phase III of the Atmospheric Modelling Subgroup of Work Group II of the Memorandum of Intent will be reviewing in detail, the ability of eight long range transport models to accurately describe the relationship between emissions of SO_2 and the deposition of sulfate.

In conclusion it is felt that Dr. Mohnen's interpretation that the "available evidence still does not reliably demonstrate that those sulphate levels can be related to the levels of SO_2 emissions sources from the Midwest", is basically incorrect and although all of the fine details concerning meteorology, atmospheric chemistry and modelling have not been worked out, it is felt that enough data are available to show that indeed sulphates are impacting the eastern States and Ontario as a result of SO_2 emissions in the midwest.

APPENDIX 14

A BRIEF REVIEW
OF OZONE/OXIDANT
INJURY TO VEGETATION
IN THE UNITED STATES

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OZONE AND VEGETATION IN NORTH AMERICA

Introduction

This report was prepared by reviewing the scientific literature in order to answer the following questions: (1) do the chemical characteristics of ozone indicate that it has phytotoxic properties; (2) do elevated concentrations of atmospheric ozone occur over large regions of North America during the growing season; (3) is ozone a cause of yield reductions in crops; and (4) what is the magnitude of recent estimates of economic losses to agriculture by exposure to ambient ozone?

Importance of ozone for vegetation

Arguments for the probable significance of ozone to plant growth and productivity fall into three categories: chemical characteristics, regional distribution, and pattern of occurrence.

Ozone is a powerful oxidizing agent with moderate solubility in water. It reacts with many compounds that have biological significance, i.e., unsaturated fatty acids and lipids, reduced pyridine nucleotides, sulfhydryl-containing compounds, and certain amino acids and proteins. The chemical reactions of ozone in biological systems can produce free radical, singlet

oxygen, or peroxy compounds that also are highly reactive. It has been demonstrated in laboratory experiments that ozone and its reaction products interfere with the functioning of critical cellular organelles including mitochondria, microsome, chloroplasts, and cell membranes. Disruption of the physiological processes of photosynthesis, respiration, stomatal movement, translocation and allocation of dry matter have been described in experiments with whole plants and plant organs. There is general agreement, then, that ozone is a phytotoxic agent (Linzon et al., 1975; National Research Council, 1976: U.S. EPA, 1978).

Chemical analysis of the atmosphere at ground level at numerous locations in North America during the last several decades has established that ozone is widely distributed because of its formation by photochemical action and its association with large air masses. The highest concentrations and greatest repetition of episodes occurs in the spring, summer, and fall seasons (National Research Council, 1976: U.S. EPA, 1978). During this time, vegetation is actively growing and more susceptible to the action of toxic air pollutants than at other times of the year. In the 6 year period from 1974 through 1979, there was no significant change in ozone concentrations in the U.S. when data from every state was evaluated. With the revised ozone National Ambient Air Quality Standard of 0.12 ppm (240 ug/m^3), one - hour

average, not to be exceeded more than one day per year, 59% of counties east of the Mississippi River were in violation, while 48% of counties west of the Mississippi were in violation of the standard (Hunt et al., 1981).

Biological effects of ozone on plants

There is an extensive literature on the production of foliar lesions, interference with growth and development, and reduction in productivity of crops and trees caused by exposure to ozone (Linzon et al., 1975; National Research Council, 1976; U.S. EPA, 1978; Macdowall, 1963; Weaver and Jackson, 1968; Pearson et al., 1974; Skelly et al., 1977; Miller and Elderman, 1977). Much of this data was obtained in studies with plants exposed to ozone in greenhouses and controlled environmental chambers. The advantage of this approach is that the variation in soil and climatic conditions is minimized and the major variable is exposure to ozone. Firm conclusions can then be drawn concerning effects on experimental plants. For example, susceptible species develop foliar lesions at a dose of approximately 0.10 ppm-hours ($200 \text{ ug/m}^3\text{-hours}$) for single exposures (National Research Council, 1976). Some of the crop plants most readily injured by ozone are: alfalfa, beans, corn, lettuce, oats, radish, soybeans, spinach, potatoes, and tobacco. There is considerable variation in susceptibility between cultivars within species.

Futhermore, production of foliar symptoms does not provide a reliable indication of the likelihood or magnitude of reductions in plant growth or yield (Jacobson, In press). Similarly, experiments with greenhouse and chamber-grown plants may over- or underestimate the response of field-grown vegetation to ambient ozone (Jacobson, In press). The order of susceptibility of tree species to ozone differs depending on whether foliar symptoms or reductions in growth are taken as the criterion (Jensen, 1973).

Reasearch performed with field-grown crops has demonstrated that decreased yield of susceptible species occurs when average ozone concentrations of between 0.05 and 0.1 ppm occur for 6-8 hours per day repeatedly during the growing season (Heck et al., 1977). Experiments performed in Maryland with ambient ozone have resulted in yield reductions of 4, 9, 10, 17, and 20% respectively for field-grown snap-beans, sweet corn, potatoes, tomatoes, and soybeans (Heggestad, 1980). These effects of ozone can be altered by the presence of other pollutants including sulphur dioxide, nitrogen dioxide, and acid rain (Reinert, 1980; Troiano et al., In press). However, the effects of mixtures of pollutants can be additive, more than additive, or less than additive depending on the concentrations and patterns of exposure and type of effect measured.

Economic impact on agriculture

Initial estimates of crop losses due to ozone and other air pollutants (National Research Council, 1976) have been supplemented by recent analyses. Nationwide losses in yield of alfalfa by ozone were estimated to be \$24 million in 1974 (Moskowitz, et al., 1981). For nine crops grown in six counties of California, consumer's losses were equivalent to \$45.7 million and producer's losses were equivalent to \$57.3 million. Total loss of sales in California were estimated at \$312.6 million with a \$131.1 million loss of value-added income. Estimated employment losses for the state were 1,192 person-years. These calculations of economic losses from yield reductions by ozone were performed for the year 1975 (Leung, et al., 1981).

Yield losses between 5 and 26% for soybeans, 4 to 15% for field corn, and 3 to 10% for wheat were estimated for the Ohio River Basin from exposures to ozone in 1977 (Loucks and Armentano, 1981). These yield reductions were converted to cumulative dollar losses for the period 1976 through 2000 amounting to approximately \$7 billion, assuming that New Source Performance Standards for power generating stations are fully implemented but State Implementation Plans are not complied with. These authors believe that compliance with State Implementation Plans will not significantly influence the amount of

agricultural losses because, in most states, there are no requirements for NO_x emissions, important precursors in the formation of ozone (Page, et al., 1981).

The recent estimate of nationwide crop losses due to ozone for the years 1969 and 1974 were \$1.3 and \$2.9 billion respectively representing about 1.5% of the total market value of crops in the U.S. These authors presented many of the qualifications that must be considered when crop losses are estimated (Moskowitz, et al., 1980). Ryan, et al., (1981), however, calculated losses from ozone to be approximately \$1.8 billion in 1980 dollars for the U.S. Benefits of meeting the ozone standards were found to be far greater than for meeting the sulphur dioxide standards.

There are wide differences in estimates of economic losses due to ozone for many reasons. The relationship between ozone exposure and yield reductions is not precisely known for crops growing under normal agronomic conditions. The frequency distributions for ozone concentrations in farming and forested areas of North America have not been adequately described. Different approaches and methods are used for conversion of yield reductions to monetary losses. Although it is clear that ambient ozone does affect crops and trees, data is not adequate to provide precise estimates of the monetary benefits of incremental reductions in ozone concentrations.

References - Appendix 14

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APPENDIX 15

CHARACTERISTICS OF THERMO-ELECTRIC POWER PLANTS IN 10
EASTERN U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

The Ten States Included in This Appendix Are:

Illinois

Indiana

Ohio

Michigan

West Virginia

Pennsylvania

Kentucky

Missouri

Tennessee

New York

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MWC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur In Coal		No. of Units	Existing FGD Systems 3)	
								1979 Avg.	SIP Objectives		Start-up Date	Reg. Class
Central Illinois Light Co.	E.D. Edwards R.S. Wallace Duck Creek	Illinois Peoria East Peoria S.E. of Canton	780	39.0%	1.80	1.28	13.8	.63	.88	FGD	Installed	
			305	17.1%	1.80	1.06	1.7	.70	1.19			
			417	48.0%	1.20	6.37	8.5	3.36	.63			
			<u>1,502</u>									
Central Illinois Public Service	Coffeen	50 mi. N.E. of St. Louis	1,005	40.1%	6.00	7.90	141.8	3.74	2.84	FGD	Installed	
	Grand Tower Hutsonville Meredosia Newton	Ill. Jackson Co., S. Ill. Crawford Co., E. Ill. W. of Springfield Newton, E. Ill.	195	49.2%	6.00	5.35	22.8	2.92	3.27			
			200	39.4%	6.00	3.32	12.4	1.83	3.30			
			564	30.3%	1.20	5.14	32.6	2.91	.68			
			<u>617</u>	61.9%	1.20	4.91	47.8	2.78	.68			
			<u>2,581</u>									
Commonwealth Edison Co.	Crawford Joliet Kincaid Pawmton Waukegan Will County Fisk Street	Chicago S.W. of Chicago Near Springfield Peoria N. of Chicago S.W. of Chicago Chicago	805	30.5%	1.80	1.07	8.0	.54	.91			
			1,838	36.6%	1.80	1.05	29.2	.50	.86			
			1,319	35.6%	6.00	6.94	136.5	3.52	3.04			
			1,786	44.5%	1.80	1.57	44.1	.79	.90			
			955	37.5%	1.80	.95	14.1	.46	.85			
			1,269	37.8%	1.80	.95	20.1	.45	.85			
			688	22.6%	1.80	.93	4.1	.43	.84			
			<u>8,660</u>									

Continued...

NB. Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MwC	Load or Capacity Factor 1)	S. I. P. Regulation Objectives (lbs. SO ₂ /million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur In Coal SIP Objectives	No. of Units	Existing FGD Systems 3)	Reg. Class
Electric Energy Inc.	Jopka	Illinois (Cont'd) Near Jopka, S. Ill.	1,041	69.0%	6.00	3.61	104.4	3.46			
	Baldwin	S.E. of St. Louis	1,800	60.4%	1.80 (4.62)	5.47 (5.21)	257.9	2.90			
	Havana	W. of Bloomington	686	22.6%	1.80	.87	4.0	.95			
	Hennepin	Putnam Co. Central Ill.	308	62.6%	6.00	4.68	34.0	3.32			
	Wood River	N. of St. Louis	650	42.8%	1.80	1.12	9.5	1.00			
			3,444								
Southern Illinois Power Corp.	Marion	Williamson Co., S. Ill.	272	41.5%	6.00	5.86	24.2	3.05	4	5/79	B
	Dallman	Sangamon Co., Central Ill.	764	NA	6.00	6.19	41.2	3.19			
			17,660				1,01.5				
			Total Ill.				Total Ill.				

Continued...

1B Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MWC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal		No. of Units	Existing FGD Systems 3)	Reg. Class
								1979 Avg.	SIP Objectives			
Commonwealth Edison Co. of Indiana	State Line	Gary	<u>764</u>	38.3%	1.20	.92	9.5	.43	.56			
	Rafts	N.E. of Evansville	<u>233</u>	NA	16.00 nfe	6.65	44.3	3.44	8.28			
Hoosier Energy, Indiana Statewide	Breed Tanners Creek	Near Fairbanks Lawrenceburg, W. of Cincinnati	450 1,098 <u>1,548</u>	56.7% 44.4%	16.00 nfe 1.20	6.76 4.29 (3.92 ⁴)	40.9	3.74	8.86			
Indiana-Kentucky Elec. Co. (owned by Ohio Valley Electric)	Citty Creek	Near Madison	<u>1,304</u>	76.3%	1.20	7.22 (6.85 ⁴)	263.7	3.95	.66			
Indianapolis Power and Light Co.	Elmer W. Stout Pritchard, H.T. Petersburg	Indianapolis S.W. of Indianapolis N.E. of Evansville	778 364 1,181 <u>2,323</u>	38.9% NA NA	1.20 16.00 nfe 16.00 nfe	3.01 3.95 5.74	44.2 18.3 100.7	1.73 2.15 3.15	.65 8.70 8.78	1	12/77	B
	(AE) = Subsidiary of American Electric nfe = not federally enforceable											

(AE) = Subsidiary of American Electric
nfe = not federally enforceable

Continued...

NB Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MMC	Load or Capacity Factor 1)	Sulfur Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulfur in Coal 1979 Avg.	SIP Objectives	No. of Units	Existing FGD Systems 3) Start-up Date	Reg. Class
Northern Indiana Public Service Co.	Battily	Indiana (Cont'd)	650	37.0%	(1.27) ⁴	5.31	58.0	3.09	8.86	1	7/76	E
	Dean H. Mitchell	Near Chesterton	582	49.5%	1.20	1.80	16.1	1.00	.67			
	Michigan City	Michigan City	661	55.2%	1.20	4.42	62.4	2.49	.45			
	Schanfer	40-50 mi. S. of Gary	521	32.6%	1.20	1.88	14.7	1.00	.63			
			2,414									
Public Service Co. of Indiana	Cayuga	Vermillion Co., W. Ind.	1,024	50.9%	16.00 nfe	4.82	121.7	2.48	8.24			
	R. Gallagher	Near Louisville, Ky.	637	49.4%	16.00 nfe	6.01	56.4	3.33	8.86			
	Wabash River	Vigo Co., W. Ind.	889	40.8%	1.20	4.09	68.5	2.23	.65			
	Gibson	Gibson	1,950	46.2%	16.00 nfe	5.34	261.1	2.86	8.58			
			4,500									
Southern Indiana Gas & Electric	Culley	Near Yanketown	415	66.0%	1.20	5.88	61.3	3.34	.65	1	3/79	B
	A.B. Brown	E. of Mt. Vernon	250	39.9%	1.20	5.77	7.67	3.24	.67			
	Warrick	Yanketown	162	54.8%	1.20	5.70	20.2	3.32	.66			
			827									
			13,913	47.8%			1,354.8					
			Ind. Total	Ind. Average			=====					

nfe = not federally enforceable

NE Footnotes and References are found at the end of the Table.

Cont Inued...

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MWC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal 1979 Avg.	No. of Units	Existing FGD Systems 3)	Reg. Class
Big Rivers Elec. Corp.	Coleman Henderson II Green	KENTUCKY Hancock Co. N.E. Ky. S. of Evansville, Oh. S. of Evansville, Oh.	455	NA	5.20	4.82	73.3	2.68		FGD Installed	
			na	NA	1.20	7.57	40.9	2.30			
			na	NA			4.7	3.82			
East Kentucky Power Coop.	Cooper #L Spurluck	S.C. Ky. Near Somerset N.W. Ky. on Ohio R.	336	NA	3.20	2.42	20.5	1.47			
			300	NA	1.20	2.14	12.8	1.23			
			636								
Kentucky Power Co. (KE) Kentucky Utilities Co.	Big Sandy E.W. Brown Ghent Green River	Louisia Harrodsburg N.E. of Louisville Muhlenberg Co. W.C.K.	1,003	63.5%	6.00	2.11	41.5	1.19	1-3	9/75	E
			706	NA	6.00	4.13	62.2	2.43			
			1,025	NA	6.00	3.37	60.1	1.89			
Louisville Gas & Electric Co.	Cane Run Mill Creek Paddy's Run	Louisville Louisville Louisville	242	NA	5.20	4.00	10.8	2.28	FGD Installed FGD Installed FGD Installed		
			1,973								
			980	40.3%	1.20	6.10	39.2	3.35			
(NE) = subsidiary of American Electric			1,079	40.0%	1.20	6.48	88.0	3.53			
			302	12.3%	1.20	6.49	5.0	3.58			
			2,361								

Continued...

NE Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MwC	Load or Capacity Factor 1)	S. I. P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal 1979 Avg.	SIP Objectives	No. of Units	Existing FGD Systems 3) Start-up Date	Reg. Class
Owensboro Municipal Utilities	Elmer Smith	KENTUCKY (Cont'd) Owensboro	415	NA	6.00	5.19	49.7	2.88	3.33			
Tennessee Valley Authority	Paradise Shawnee	Muhlenberg Co., W.C. Ky. McCracken Co. W. Ky.	2,558 1,750 4,308	49.6% 48.6% 47.2% =====	5.20 1.20	8.27 3.56	372.5 111.0	4.35 2.03	2.73 0.68			
		Ky. Total 11,151+ =====		Ky. Avg.								
New England Electric	Brayton Point (Oil Plant)	MASSACHUSETTS S. Mass., Next to R2 Border	1,611	65.3%	1.20	3.90	79.3	2.1 in coal no oil used				
New England Power Co.	Salem Harbour	N.W. of Boston (Salem)	2,416 2,416 =====	49.8% 60.1% =====	1.20	3.90	35.9	2.63				
		Mass. Total		Mass. Avg.								

NE Footnotes and References are found at the end of the Table.

Continued...

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MwC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal		No. of Units	Existing FSD Systems 3) Start-up Date	Reg. Class
								1979 Avg.	SIP Objectives			
Consumers Power Co.	B.C. Cobb	MICHIGAN Muskegon	511	67.4%	1.50 (1.00) ⁴	2.58 (4.23) ⁴	69.3	2.58	1.50			
	D.E. Karn	Bay Co., on Saginaw Bay	1,761	49.0%	1.50	2.24	53.4	2.24	1.50			
	J.H. Campbell	S. of Muskegon	671	62.9%	1.50	2.18 (3.68) ⁴	57.0	2.18	1.50			
	J.C. Weadock	Bay Co., on Saginaw Bay	635	34.0%	1.50	2.24	29.2		gas-fueled plant			
	J.R. Whiting	S. of Detroit	346	67.4%	1.50	.82	12.3	.81	1.49			
Detroit Edison Co.	Conners Creek	Detroit	604	20.2%	SIP objectives only		6.4	.79	1.26			
	Marysville	Port Huron	228	42.8%	concerning sulphur		4.5	.80	1.50			
	Monroe	S. of Detroit	3,014	56.1%	content in coal		264.8	2.37	1.20			
	River Rouge	Detroit	787	50.1%			16.5	.79	1.50			
	St. Clair	St. Clair	1,754	51.4%			39.7	.67	1.49			
City of Lansing Board of Water and Light Upper Peninsula	Trenton Channel	Detroit	720	65.1%			23.2	.92	1.00			
			7,107									
	Eckert Station	Lansing	380	NA	" "	" "	9.1	1.00	1.49			
	Presque Isle	Marquette	507	56.6%			15.6	.57	1.49			
			11,918	52.3%			601.0					
			Mich. Total									

Continued...

NB Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MwC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur In Coal 1979 Avg.	SIP Objectives	No. of Units	Existing FGD Systems 3) Start-up Date	Reg. Class
Associated Electric Coop.	New Madrid Thomas Hill	MISSOURI New Madrid Co., S.E. Mo. Randolph Co., N.C. Mo.	1,200	48.6%	16,00 n.f.e.	5.87	164.0	3.16	8.62			
			483 <u>1,683</u>	46.8%	16,00 n.f.e.	8.90	104.9	4.32	7.76			
Empire District Electric Co.	Asbury	Jasper Co., S.W. Mo.	200	70.0%	16,00 n.f.e.	9.23	50.8	4.82	8.35			
Kansas City Power and Light	Hawthorne Montrose	Kansas City S.E. of Kansas City	760	32.7%	16,00 n.f.e.	3.26	27.6	1.88	9.24			
			527 <u>1,287</u>	54.2%	16,00 n.f.e.	11.30	147.1	5.36	7.59			
Missouri Public Service St. Joseph Light and Power	Sibley Lake Road	Kansas City St. Joseph	524	40.8%	16,00 n.f.e.	6.45	15.5	3.81	9.46			
			236	48.0%	16,00 n.f.e.	7.95	23.5	4.32	8.69			
Union Electric	Labadie Meramec Sioux Rush Island	Franklin St. Louis St. Charles Jefferson, new St. Louis	2,220	61.9%	16,00 n.f.e.	4.14	224.0	2.31	8.94			
			800	46.5%	2.30	2.13	27.6	1.34	1.45			
			978	44.7%	2.30	3.69	83.7	2.03	1.27			
			1,110 <u>5,108</u> =====	63.2%	SIP objective only concerning % sulphur. In coal	43.8 <u>958.1</u> =====	Mo. Total	.90	2.00			
n.f.e. = not federally enforceable												

MB Footnotes and References are found at the end of the Table.

Continued...

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MWC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur In Coal		No. of Units	Existing FGD Systems 3)	
								1979 Avg.	SIP Objectives		Start-up Date	Reg. Class
Atlantic City Electric Co.	B.L. England	NEW JERSEY Cape May Co., S. N.J.	476	62.2%	SIP objective only concerning % sulphur in coal		40.2	2.98	1.00			
	Deepwater	Salem Co., S.W. N.J.	327	35.6%	NA	NA	4.5	1.22 (oil)	NA			
Public Service Elec. & Gas Co.	Bergen (oil plant)	N. of Jersey City	712	NA	NA	NA	1.5	.27	NA			
	Hudson	Jersey City	1,230	NA	SIP objective only concerning % sulphur in coal		16.3	1.19	0.20			
	Mercer	Trenton	768	NA			18.3	1.27	0.20			
			2,710	51.4%			80.8					
			3,513	N.J. Avg.			N.J. Total					
New York State Electric & Gas Corp.	Milliken	NEW YORK Ithaca	276	NA	1.90 (lbs. S/mill. BTU)	1.52 (lbs S ₂ /mill BTU)	23.2	1.76				
	Huntley Creek	Buffalo	720	57.5%	1.40 (lbs. S/mill. BTU)	1.19 (lbs S/mill. BTU)	42.7	1.54				
Niagara Mohawk Power	Dunkirk	On Lk Erie at Penn. Border	629	61.5%	1.90 (lbs. S/mill. BTU)	1.69 (lbs S/mill. BTU)	54.4	2.14				
			1,349									

Continued...

NB Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MwC	Load or Capacity Factor 1)	S. I. P., Regulation Objectives (lbs. SO ₂ /million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	\$ Sulphur In Coal SIP Objectives	No. of Units	Existing FGD Systems 3) Start-up Date	Reg. Class
Rochester Gas & Electric & Gas Corp.	Station #3	NEW YORK Rochester	215	32.1%	1.90 (lbs S/mill., BTU)	2.12 (lbs S/mill., BTU)	10.4	2.67			
	Station #7	Rochester	253 468 ----- N.Y. Total	63.8% 56.8% ----- N.Y. Avg.	1.90 (lbs S/mill., BTU)	1.84 (lbs S/mill., BTU)	22.7 153.4 ----- N.Y. Total	2.32			
Columbus & Southern Ohio Electric Co.	Conesville	OHIO Conesville, C. Oh.	1,347	63.3%	5.66	7.89	186.8	4.36	2	1/77	D
	Poston	Nelsonville, S. Oh.	240 1,787	24.7%	3.72 (3.94) ⁴	7.05	29.8	3.92		1/78	
Dayton Power & Light Co.	Frank M. Tait Hutchings	Dayton	460	32.7%	1.25	1.02	4.1	.62			
	J.M. Stuart	Dayton S. Oh. on Ohio R.	447 858 1,765	51.6% 52.5%	1.20 3.16	1.01 2.20	7.0 125.6	.62 1.22			
Ohio Edison Co.	Edgewater Niles	W. of Cleveland Trumbull Co., E. Oh.	193 280	51.9% 54.6%	1.70 5.41	4.25 5.19	17.1 30.9	2.51 3.13			
	R.E. Burger W.H. Sammis	Belmont Co., E. Oh. Stenbenville	950 1,990 3,013	53.2% 39.4%	16.00 n.f.o.	6.01 3.93	79.0 160.7	3.64 2.35			

(AE) = subsidiary of American Electric

NB Footnotes and References are found at the end of the Table.

Continued...

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MwC	Load or Capacity Factor 1)	S. I. P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur In Coal 1979 Avg.	No. of Units	Existing FGD Systems 3) Start-up Date	Reg. Class
Ohio Electric (AE)	Gavin	OHIO (Cont'd) Gallia Co., S.Oh.	2,600	64.3%	9.50	4.91	339.5	2.40	4.65		
	Muskingum	Morgan Co., S.E. Oh.	<u>1,467</u>	58.7%	6.48	9.90	340.2	5.19	3.40		
	Kyger Creek	Gallia Co., S.E. Oh.	<u>1,086</u>	NA	8.20	6.83	205.5	3.83	4.60		
Toledo Edison	ADME Bay Shore	Toledo Toledo	308 640 <u>948</u>	31.3% 73.2%	3.00 1.20	3.70 1.48	14.5 23.7	2.23 .94	1.81 .76		
			20,177	50.6%			2,211.3				
			Oh. Total	Oh. Avg.			Oh. Total				
Duquesne Light Company	Frank R. Phillips	PENNSYLVANIA Pittsburg	315	42.4%	.70	3.64	6.7	2.18	1-6	7/73	D
	Cheswick	Pittsburg	525	63.5%	.60	2.96	41.8	1.78	1-4	10/75	D
	Eitrams	S. of Pittsburg	<u>425</u> <u>1,265</u>	57.5%	.67	3.53	10.4	2.06			

Continued...

(AE) - subsidiary of American Electric
NB Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MMC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal		No. of Start-up Units	Existing FGD Systems 3)	Reg. Class
								1979 Avg.	SIP Objectives			
Metro Edison (G.P.U.)	Portland Titus	PENNSYLVANIA (Cont'd) Northampton Co., E. Penn Reading, E.C. Penn.	427	61.5%	1.80	3.49	25.7	2.20				
			225	67.7%	2.03	1.92	12.5	1.22				
			<u>652</u>									
Pennsylvania Electric (G.P.U.)	Conemaugh Homer City Seaward Shawville Keystone	E. of Pittsburgh E. of Pittsburgh E. of Pittsburgh Shawville, W.C. Penn N.E. of Pittsburgh	308	46.8%	4.00	3.89	108.9	2.36				
			1,006	48.5%	4.00	3.38	159.1	1.94				
			280	47.9%	4.00	3.77	23.0	2.32				
			640	70.4%	4.00	3.38	64.6%	2.07				
			231	53.8%	4.00	2.99	127.2	1.77				
			<u>2,465</u>									
Pennsylvania Power & Light Co.	Brunner Island Martin's Creek Montour Snyder	S. of Harrisburg Northampton Co., E. Penn Montour Co., C. Penn Snyder Co., C. Penn	1,559	65.6%	4.00	3.47	142.00	2.17				
			2,444	36.0%	4.00	3.45	25.0	2.18				
			1,642	62.5%	4.00	2.56	109.4	1.61				
			410	68.0%	4.00	2.38	36.7	1.48				
			<u>6,055</u>									
Pennsylvania Power Co.	New Castle Bruce Mansfield	Lawrence Co., W. Penn N.W. of Pittsburgh	426	88.8%	*72	2.64	25.2	1.62		1	12/75	
			92	40.0%	1.20	5.48	84.9	3.19		2	7/77	
			<u>518</u>							3	6/80	

(G.P.U.) = subsidiary of General Public Utilities

NB Footnotes and References are found at the end of the Table.

Continued...

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MWC	Load or Capacity Factor 1)	S, I, P, Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2) 10 ³ Metric Tonnes, 1979	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal		No. of Units	Existing FGD Systems 3) Start-up Date	Reg. Class	
								1979 Avg.	SIP Objectives				
Philadelphia Electric Co.	Cromby Eddystone	PENNSYLVANIA (Cont'd) W. of Philadelphia W. of Philadelphia	351	65.0%	.62	3.56	12.1	2.33					
			1,395	35.9%	.60	3.73	42.0	2.42					
			<u>1,746</u>										
West Pennsylvania Power Co. (APS)	Armstrong Hatfield's Ferry Mitchell	N.E. of Pittsburgh Greene Co., S.W. Penn S.W. of Pittsburgh	326	62.9%	4.00	3.23	37.1	1.96					
			907	42.4%	4.00	4.12	167.3	2.48					
			449	21.6%	.60	3.12	28.4	2.04					
			<u>1,682</u>				<u>1,290.2</u>						
			14,389	<u>52.2%</u>			=====	=====					
			Pa Total	Pa Avg.			Pa Total						
Tennessee Valley Authority	Thomas H. Allen Bull Run Cumberland Gallatin John Sevier Johnsonville Kingsston Watt's Bar	TENNESSEE Memphis N.E. of Knoxville Stewart Co., N. Tenn N.E. of Nashville Hawkins Co., N.E. Tenn Humphreys Co., W.C. Tenn W. of Knoxville Rhea Co., C. Tenn	990	41.2%	4.00	3.85	61.2	2.26					
			990	72.6%	4.00	1.68	32.1	0.94					
			2,600	43.4%	5.00	6.36	289.7	3.44					
			1,255	54.0%	5.00	4.34	110.6	2.59					
			847	70.1%	4.00	3.10	62.0	1.83					
			1,485	49.6%	1.20	5.54	157.9	3.10					
			1,723	63.0%	1.20	2.05	87.2	1.27					
			240	48.2%	4.00	3.43	12.0	1.98					
			<u>10,090</u>	<u>53.9%</u>			<u>812.7</u>						
			=====	=====			=====						
			Tenn Total	Tenn Avg.			Tenn Total						
(APS) = subsidiary of Allegheny Power System													

Continued...

NB Footnotes and References are found at the end of the Table.

CHARACTERISTICS OF THERMO-ELECTRIC POWER
PLANTS IN 10 U.S. STATES WITH A CAPACITY OF 200 MW OR GREATER

Company	Plant	Location	Generation Capacity MWC	Load or Capacity Factor 1)	S.I.P. Regulation Objectives (lbs. SO ₂ /Million Btu)	Present SO ₂ Emissions 2)	SO ₂ Emissions 10 ³ Metric Tonnes, 1979	% Sulphur in Coal		No. of Units	Existing FGD Systems 3)	
								1979 Avg.	SIP Objectives		No. of Start-up Date	Reg. Class
Appalachian Power Co. (AE)	John E. Amos Kanawha River	WEST VIRGINIA Charleston Charleston	2,775	47.6%	2.01	1.36	102.5	.81	1.19			
			426	71.4%	1.61	1.29	105.2	.74	.93			
			<u>3,201</u>									
Central Operating Co.	Phil Sporn	Mason Co., W. Va.	1,060	48.4%	3.30	1.68	32.7	.96	1.89			
Monongahela Power Company (APS)	Pleasants Albright Fort Martin Harrison Willow Island	Pleasants Co., W. Va. Preston Co., N. Va. N. of Morgantown Clarksburg	NA	NA	1.20	4.43	8.9	2.75	.74	FGD	Installed	
			209	71.7%	4.42	2.66	23.5	1.61	2.68			
			259	51.5%	3.20	3.06	94.6	1.85	1.94			
			513	58.3%	4.11	3.97	142.8	2.57	2.66			
			<u>215</u>	51.3%	3.76	2.14	11.6	1.30	2.28			
			<u>1,196+</u>									
Ohio Power Co. (AE)	Kammer Mitchell	In "Panhandle" N. W. Va. In "Panhandle" N. W. Va.	675	54.3%	3.20	7.24 (313) ⁴	136.8	4.31	1.90			
			1,498	61.0%	3.12	5.38	186.2	3.21	1.86			
			<u>2,173</u>									
Virginia Electric and	Mt. Storm	Grant Co., E.C. W. Va.	1,681	46.5%	2.90	3.37	102.5	1.93	1.66			
			9,311+	52.5%								
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154									
			Plants									
			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
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			125,937									
			<u>W. Va. Total</u>	<u>W. Va. Avg.</u>								
			11 154								</	

FOOTNOTES AND REFERENCES FOR APPENDIX 15

Footnotes

- 1) Load or Capacity Factor was calculated by dividing the electricity produced in one year (given in MWHrs) by the hours in one year and then dividing the quotient by the generation capacity.
- 2) Source document: U.S. Department of Energy, Energy Information Administration. Cost and Quality of Fuels for Electric Utility Plants - 1979 June, 1980 DOE/EIA - 0191 (79).
- 3) According to "U.S. Power Plants Survey for 1979", supplied by MOE, Air Resources Branch, FGD system is in place. No details concerning the system are available.
- 4) The footnoted number is based on data supplied by MOE, Air Resources Branch. The other numbers in the column are from U.S. Department of Energy, Cost and Quality of Fuels for Electric Utility Plants - 1979.

Sources

Electrical World, Directory of Electric Utilities, 1979 - 1980, 88th Edition. New York: McGraw Hill Pub. Co., 1979.

Moody's Public Utility Manual, 1980, Vol. 1 & 2.

U.S. Department of Energy, Energy Information Administration, Cost and Quality of Fuels for Electric Utility Plants - 1979. June, 1980, DOE/EIA - 0191(79).

"U.S. Power Plants' Survey for 1979". Tables compiled by MOE, Air Resources Branch, 1981.

APPENDIX 16

ESTIMATES OF THE COSTS OF USING LOW SULPHUR COAL TO MEET
1979 S.I.P. EMISSION OBJECTIVES COMPARED TO SCRUBBING IN
ASSOCIATION WITH HIGH SULPHUR COAL.

TABLE 16-1
Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal¹

Columns/1	ILLINOIS					
	2	3	4	5	6	7
Plant	Actual Cost of Coal ¹⁾ (mills/kwh)	Average %S in Coal 1979 (%)	S to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objective (mills/kwh)	Money Available to Buy Coal ²⁾ (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
E.D. EDWARDS	17.19	0.63	0.884	16.6	10.6	3.4
R.S. WALLACE	19.47	0.70	1.193	15.3	9.3	4.6
DUCK CREEK	14.33	3.36	0.633	18.1	12.1	2.4
COFFEEN	10.10	3.74	2.841	11.4	5.4	11.0 ³⁾
GRAND TOWER	11.03	2.92	3.273	10.8	4.8	12.6 ³⁾
HUTSONVILLE	11.78	1.83	3.304	10.7	4.7	12.9 ³⁾
MEREDOSIA	13.46	2.91	0.680	17.8	11.8	2.6
NEWTON	13.93	2.78	0.680	17.8	11.8	2.6
CRAWFORD	18.13	0.54	0.910	16.5	10.5	3.5
JOLIET	17.07	0.50	0.856	16.7	10.7	3.3
KINCAID	12.00	3.52	3.043	11.1	5.1	11.7 ³⁾
POWERTON	16.78	0.79	0.904	16.5	10.5	3.5
WAUKEGAN	14.60	0.46	0.868	16.7	10.7	3.3
WILL COUNTY	19.29	0.45	0.849	16.8	10.8	3.3
FISK STREET	19.47	0.43	0.836	16.8	10.8	3.3
JOPPA STEAM	13.12	2.08	3.455	10.5	4.5	13.3 ³⁾
HAVANA	19.43	0.54	1.117	15.6	9.6	4.3
HENNEPIN	13.14	2.59	3.320	10.7	4.7	12.9 ³⁾
WOOD RIVER	17.27	0.62	1.004	16.0	10.0	3.9
DALMAN	11.67	3.29	3.191	10.9	4.9	12.3 ³⁾
MARION	9.46	3.05	3.128	11.0	5.0	12.0 ³⁾

1) 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S. DOE, 1979.

2) Cost of coal to meet SIP 1979, less cost of scrubbing (6 mills/kwh).

3) Estimated Coal S content greater than range of actual data.

TABLE 16-2

Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal

INDIANA						
Columns/1	2	3	4	5	6	7
Plant	Actual Cost of Coal 2) (mills/kwh)	Average %S in Coal 1979 (%)	S to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objectives (mills/kwh)	Money Available to Buy Coal 2) (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
RATTS	7.38	3.44	8.28	2.12	N.A. 3)	N.A. 3)
STOUT ELMERN	10.26	1.73	0.65	21.65	15.65	1.76
PRITCHARD H.T.	11.32	2.15	8.70	1.74	N.A. 3)	N.A. 3)
PETERSBURGH	8.99	3.15	8.78	1.67	N.A. 3)	N.A. 3)
BAILLY	13.63	3.09	8.86	1.60	N.A. 3)	N.A. 3)
MITCHELL, DEAN H.	17.77	1.00	0.67	21.42	15.42	1.81
MICHIGAN CITY	13.07	2.49	0.45	24.48	18.48	1.14
SCHAFER	17.18	1.00	0.63	21.89	15.89	1.71
CAYUGA	8.85	2.48	8.24	2.16	N.A. 3)	N.A. 3)
GALLAGHER, R.	10.35	3.33	8.86	1.60	N.A. 3)	N.A. 3)
WABASH RIVER	10.45	2.23	0.65	21.65	15.65	1.76
GIBSON	10.67	2.86	8.58	1.85	N.A. 3)	N.A. 3)
CULLEY	8.44	3.34	0.65	21.65	15.65	1.76
A.B. BROWN	14.10	3.24	0.67	21.42	15.42	1.81
WARRICK	9.86	3.32	0.66	21.54	15.54	1.79
STATE LINE	17.34	0.43	0.56	22.80	16.80	1.51
CLIFTY CREEK	9.40	3.95	0.66	21.54	15.54	1.79
BREED	11.39	3.74	8.86	1.60	N.A. 3)	N.A. 3)
TANNERS CREEK	15.36	2.37	0.66	21.54	15.54	1.79

1) 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S. DOE, 1979.

2) Cost of coal to meet SIP (1979) less cost of scrubbing (6 mills/kwh).

3) N.A. = Cost of coal is below the 6 mills for scrubbing, therefore scrubbing is not least cost.

TABLE 16-3

Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal

KENTUCKY

Columns/1	2	3	4	5	6	7
Plant	Actual Cost of Coal 1) (mills/kwh)	Average %S in Coal 1979 (%)	S to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objectives (mills/kwh)	Money Available to Buy Coal 2) (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
COLEMAN	9.44	2.68	2.89	9.89	3.89	6.91
HENDERSON II	10.21	2.30	2.88	9.91	3.91	6.89
GREEN	10.08	3.82	0.61	20.59	14.59	1.46
COOPER	11.65	1.47	1.95	12.59	6.59	4.67
SPURLOCK H.L.	12.22	1.23	0.69	19.74	13.74	1.65
BROWN, E.W.	11.72	2.43	3.53	8.51	2.51	8.45
GHEAT	13.16	1.89	3.36	8.85	2.85	8.04
GREENRIVER	10.42	2.28	2.97	9.70	3.70	7.11
CANE RUN	10.31	3.35	0.66	20.04	14.04	1.58
MILL CREEK	10.52	3.53	0.65	20.15	14.15	1.56
PADDY'S RUN	10.07	3.58	0.66	20.04	14.04	1.58
ELMER SMITH	12.25	2.88	3.33	8.91	2.91	7.97
PARADISE	7.83	4.35	2.73	10.28	4.28	6.53
SHAWNEE	14.92	2.03	0.68	19.84	13.84	1.63
BIG SANDY	11.83	1.19	3.39	8.79	2.79	8.11

1) 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S. DOE, 1979.

2) Cost of coal to meet SIP (1979), less cost of scrubbing (6 mills/kwh).

TABLE 16-4

Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal

MICHIGAN

Columns/1	2	3	4	5	6	7
Plant	Actual Cost of Coal 1) (mills/kwh)	Average %S in Coal 1979 (%)	S to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objectives (mills/kwh)	Money Available to Buy Coal 2) (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
COBB, B.C.	13.46	2.58	1.50	13.79	7.79	7.93
KARN, D.E.	13.26	2.24	1.50	13.79	7.79	7.93
CAMPBELL	12.97	2.18	1.50	13.79	7.79	7.93
WEADOCK	Burns Gas	-	-	-	-	-
WHITING	15.41	0.81	1.49	13.81	7.81	7.88
CONNORS CREEK	16.19	0.79	1.26	14.42	8.42	6.66
MARYSVILLE	15.41	0.80	1.50	13.79	7.79	7.93
MONROE	13.16	2.37	1.20	14.59	8.59	6.35
RIVER ROUGE	15.70	0.79	1.50	13.79	7.79	7.93
ST. CLAIR	13.36	0.67	1.49	13.81	7.81	7.88
TRENTON CHANNEL	15.99	0.92	1.00	15.25	9.25	5.29
ECKERT STATION	16.87	1.01	1.49	13.81	7.81	7.88
PRESQUE ISLE	15.99	0.57	1.49	13.81	7.81	7.88

1) 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S., DOE, 1979.

2) Cost of coal to meet SIP (1979), less cost of scrubbing (6 mills/kwh).

TABLE 16-5

Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal

MISSOURI

Columns/1	2	3	4	5	6	7
Plant	Actual Cost of Coal ¹⁾ (mills/kwh)	Average %S in Coal 1979 (%)	\$ to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objectives (mills/kwh)	Money Available to Buy Coal ²⁾ (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
NEW MADRID	9.75	3.16	8.62	3)	3)	3)
THOMAS HILL	9.41	4.32	7.76	3)	3)	3)
ASHBURY	7.70	4.82	8.35	3)	3)	3)
HAWTHORNE	8.37	1.88	9.24	3)	3)	3)
MONTROSE	7.89	5.36	7.59	3)	3)	3)
SIBLEY	11.40	3.34	9.05	3)	3)	3)
JAMES RIVER	11.66	3.81	9.46	3)	3)	3)
LAKE ROAD	13.19	4.32	8.69	3)	3)	3)
LABADIE	8.69	2.31	8.94	3)	3)	3)
MERAMEC	15.54	1.34	1.45	16.16	10.16	2.94
STOUX	11.12	2.03	1.27	17.29	11.29	2.57
RUSH ISLAND	13.11	0.90	2.00	13.43	7.43	4.05

¹⁾ 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S. DOE, 1979.²⁾ Cost of coal to meet SIP (1979), less cost of scrubbing (6 mills/kwh).³⁾ Plant already meets S.I.P. objective.

TABLE 16-6
Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal

OHIO						
Columns/1	2	3	4	5	6	7
Plant	Actual Cost of Coal 1) (mills/kwh)	Average %S in Coal 1979 (%)	S to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objectives (mills/kwh)	Money Available to Buy Coal 2) (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
CARDINAL	11.79	1.81	2.75	11.89	5.89	9.37
BECKJORD	11.83	2.35	1.08	16.46	10.46	3.68
MIAMIFORT	12.35	1.96	1.83	13.88	7.88	6.24
ASHTABULA	12.51	3.79	2.97	11.51	5.51	10.13 3)
AVON LAKE	13.71	2.58	1.01	16.79.	10.79	3.44
EAST LAKE	14.61	3.26	0.85	17.63	11.63	2.90
LAKESHORE	16.78	0.70	1.14	16.20	10.20	3.88
CONESVILLE	10.76	4.36	3.13	11.25	5.25	10.68 2)
POSTON	9.01	3.92	2.07	13.28	7.28	7.05
FRANK M. TAIT	15.58	0.62	0.76	18.18	12.18	2.59
HUTCHINGS	15.72	0.62	0.73	18.38	12.38	2.49
STUART, J.M.	13.08	1.22	1.75	14.10	8.10	5.97
EDGEWATER	13.01	2.51	1.00	16.84	10.84	3.41
NILES	9.83	3.13	3.26	11.06	5.06	11.11 2)
BURGER, R.E.	14.20	3.64	9.69	5.73	N.A.	N.A.
SAMMIS	12.22	2.35	1.74	14.13	8.13	5.93
KYGER CREEK	10.34	3.83	4.60	9.37	3.37	15.69 3)
ACME	14.04	2.23	1.81	13.93	7.93	6.17
BAYSHORE	16.36	0.94	0.76	18.81	12.18	2.59
MUSKINGUM	10.97	5.19	3.40	10.85	4.85	11.59 3)
GAVIN	16.01	2.40	4.65	9.32	3.32	15.85 2)

1) 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S. DOE, 1979.

2) Cost of coal to meet SIP (1979), less cost of scrubbing (6 mills/kwh).

3) Estimated coal S content greater than range of actual data.

TABLE 16-7

Data Sets and Results - Comparing Low Sulphur Coal Costs with FGD in Association with Burning High Sulphur Coal

WEST VIRGINIA

Columns/1	2	3	4	5	6	7
Plant	Actual Cost of Coal ¹⁾ (mills/kwh)	Average %S in Coal 1979 (%)	S to meet 1979 SIP Regulation (%)	Estimated Cost of Coal to meet 1979 S.I.P. Objectives (mills/kwh)	Money Available to Buy Coal ²⁾ (mills/kwh)	Sulphur in Coal that can be purchased with Scrubbing (%)
MT. STORM	11.61	1.93	1.66	12.27	6.27	4.95
AMOS, JOHN E.	14.44	0.81	1.19	14.10	8.10	3.55
KANAWA RIVER	11.93	0.74	0.93	15.45	9.45	2.77
ALBRIGHT	10.07	1.61	2.68	9.64	3.64	7.99
FORT MARTIN	12.00	1.85	1.94	11.41	5.41	5.79
HARRISON	11.63	2.57	2.66	9.68	3.68	7.93
WILLOW ISLAND	13.79	1.30	2.28	10.53	4.53	6.79
KAMMER	7.37	4.31	1.90	11.53	5.53	5.66
MITCHELL	12.48	3.21	1.86	11.65	5.65	5.54
SPORN PHIL	15.26	0.96	1.89	11.56	5.56	5.63
PLEASANTS	11.84	2.75	0.74	16.71	10.71	2.21

¹⁾ 1979 Cost from Cost and Quality of Fuels for Electric Utility Plants, U.S. DOE, 1979.²⁾ Cost of coal to meet SIP (1979), less cost of scrubbing (6 mills/kwh).



ACID GAS CONTROL PROGRAM STATUS REPORT

As Of May 31, 1981

This quarterly report provides information on the progress of Ontario Hydro's Acid Gas Control Program, developed to comply with the provincial acid gas emission requirements of Ontario Regulation 73/81 made under The Environmental Protection Act, 1971.

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PURPOSE OF THE REPORT

This report describes Ontario Hydro's Acid Gas Control Program and provides information on the status of the program. It also provides information on Hydro's acid gas emission levels.

This report will be issued on a quarterly basis. Persons interested in further information on the program are asked to contact R.J. Taborek, Coordinator, Acid Gas Control Program, Ontario Hydro, 700 University Avenue, Toronto, Ontario, M5G 1X6.

BACKGROUND

In a joint announcement on January 26, 1981, the Honourable Harry C. Parrott, Ontario Minister of the Environment announced objectives to limit the total annual emission of sulphur dioxide and nitric oxide by Ontario Hydro to 450,000 tonnes by 1986 and to 300,000 tonnes by 1990. Mr. Hugh Macaulay, Chairman of Ontario Hydro, announced at the same time that Ontario Hydro would meet these objectives and outlined a program which would permit Ontario Hydro to achieve these limits.

In February 1981, Ontario Regulation 73/81 made under the Environmental Protection Act, 1971 was enacted to limit Ontario Hydro's sulphur dioxide emissions to 390,000 tonnes by 1986 and to 260,000 tonnes by 1990, and nitric oxide emissions to 60,000 tonnes by 1986 and to 40,000 tonnes by 1990.

Ontario Hydro's fossil-fired generating stations typically emit about 20% of Ontario's sulphur dioxide emissions but contribute only about 3-5% of depositions in the sensitive areas of the Province. About 60-85% of the deposition in these areas originate in the United States. Figure 1 shows the relative contribution to acidic deposition around the Great Lakes area from U.S., Canada and Ontario Hydro sources in a typical year.

Ontario Hydro's annual acid gas emissions for the period 1960-1980, including sulphur dioxide and nitric oxide emissions, are shown in Figure 2. During this period, acid gas emissions generally increased as a result of fossil-fired generation added to the system. Fossil-fired generation in this report, includes gas-fired, oil-fired but mostly coal-fired generation. In the early 1970s, emissions declined because of burning gas rather than coal at Hearn Generating Station, and the addition of Pickering A Nuclear Generating Station to the system. After 1975, emissions increased once again year after year. However, during the late 1970s, the rate of increase in emissions decreased even with relatively high exports because of decreased growth of demand, purchase of low sulphur coal and the addition of Bruce A Nuclear Generating Station. Gas-fired

and oil-fired generation were reduced to very low levels and reduction in demand for fossil generation resulted in mothballing of a number of these units.

Fossil fuel is the swing fuel of Hydro's system and is generally used to meet peak and intermediate loads. Fossil consumption, and consequently acid gas emissions, is expected to vary considerably depending on the demand for electricity and the supply from non-fossil generation. The demand for electricity varies with the weather, the economy and the level of exports. Fossil generation then meets the demand not supplied by imports, hydraulic and nuclear generation. As a result, the variability of acid gas emissions is higher than the variability of either the demand or the non-fossil supply.

Ontario Hydro is developing a 10 year program to reduce acid gas emissions from coal-fired generating stations. The program takes the general approach of reducing the total annual emissions from Hydro's stations rather than imposing specific limits on individual generating units. It allows Ontario Hydro the flexibility to consider a broad range of control measures, and select the most cost effective for implementation, thereby minimizing the cost impact on the electricity user.

The January 26, 1981 announcement by Mr. Macaulay provides the general description of the Acid Gas Control Program. Various components of the program are now being defined, developed and integrated into an overall implementation plan. Since the demand for fossil generation may vary considerably in the future, the program will be dynamic and periodic adjustments will be made to ensure that the regulations are met in the face of changing circumstances, such as changes in load growth or the availability of other forms of generation.

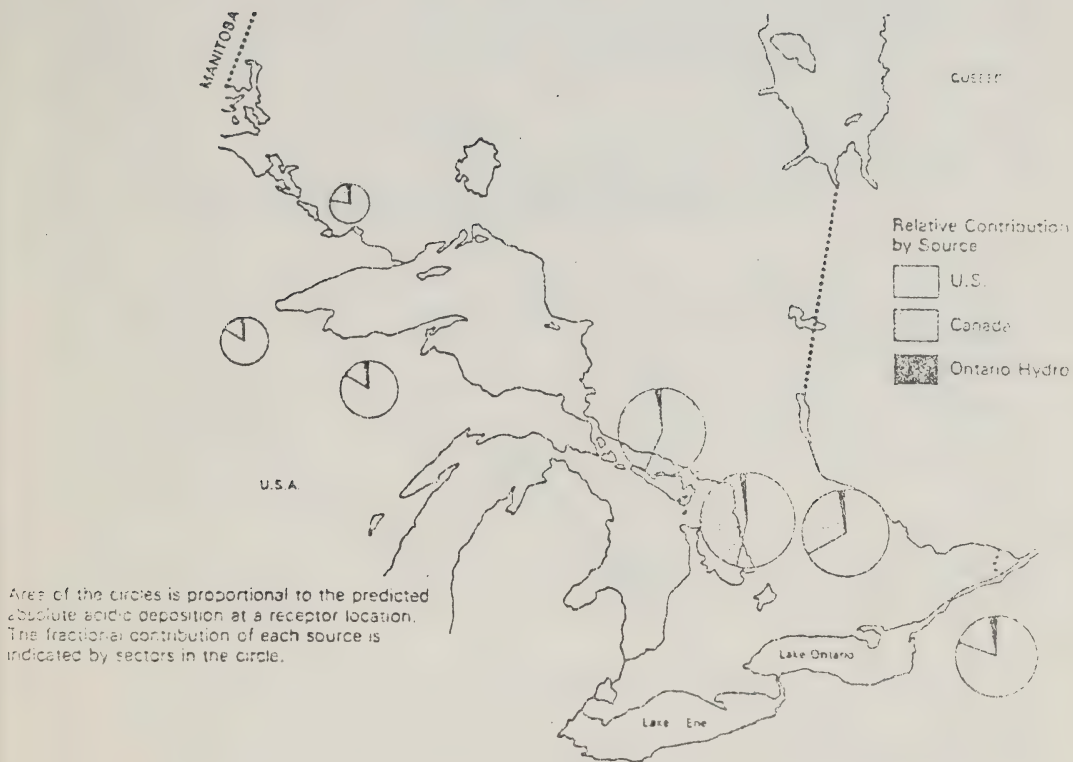
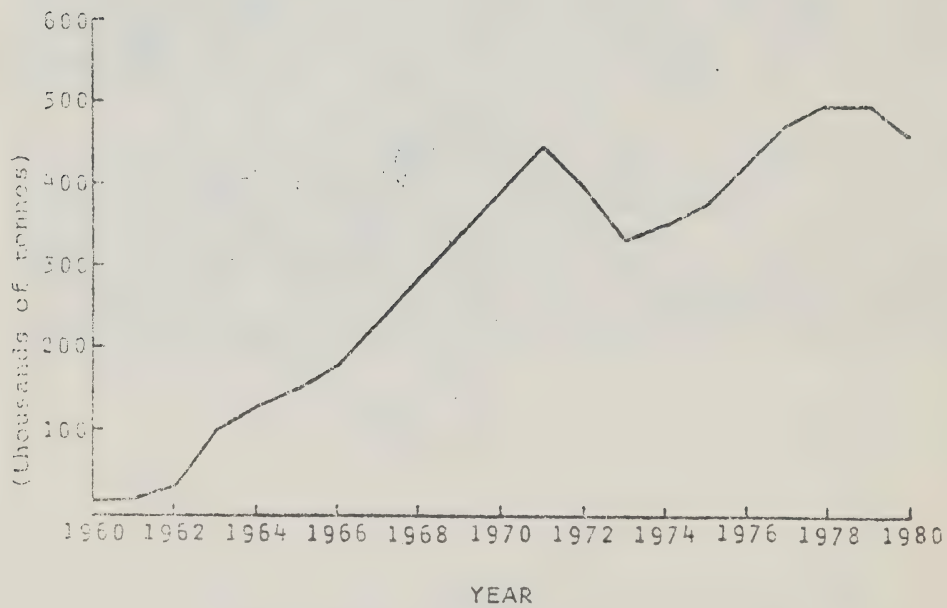


Figure 1
Acidic Deposition at Selected Receptor Areas
from U.S., Canada and Ontario Hydro
in a typical year based on 1978 data

Figure 2

Ontario Hydro's Acid Gas Emissions
1960 - 1980



PROGRAM COMPONENTS

The Acid Gas Control Program is an extension of Ontario Hydro's present program, begun in the early 1970s, to meet local air quality regulations around fossil generating stations. The efforts to date consist of purchases of low sulphur and washed coal. To reduce sulphur dioxide emissions, low sulphur coal is acquired from the U.S. and Western Canada. All coal under contract is washed, at an additional cost, to reduce ash and sulphur content. The average sulphur content of all coal purchased has decreased from about 2.5% in 1971-1976 to 1.7% in 1980.

The control program announced in January 1981 has a number of components, which will be incorporated in varying degrees to meet changing circumstances. These components are:

- (1) Design and install flue gas scrubbers on two 500 MW units at Lambton Generating Station or Nanticoke Generating Station. These scrubbers will remove about 90% of the sulphur dioxide from the flue gas stream. The scrubber is a major chemical plant attached to an already complex generating unit. Limestone is the scrubbing agent to remove the sulphur and residue will be produced. Environmental approval will be necessary to deal with the disposition of the residue unless it can be transformed into a saleable product such as gypsum.
- (2) Modify the burners at Nanticoke, Lakeview and Lambton Generating Stations to reduce nitric oxide emissions by 25% overall. Testing at Nanticoke Generating Station began in 1980.
- (3) Purchase additional hydroelectric energy from Manitoba and Quebec. The amount of purchase depends on need, economics and availability. However, existing interconnections and internal transmission may limit Hydro's import capacity.
- (4) Increase purchases of low-sulphur coal.

Milestones of the development of the four components of the Acid Gas Control Program are shown in the next section. The new program is estimated to cost a total of about \$500 million in the period from 1981 to 1990. It is designed to achieve the emission reduction targets stated in the regulations. It is based on several factors, and should these factors change, the Acid Gas Control Program would be revised to meet the emission targets. The factors are:

- (1) A load growth projection averaging 3.1% annually to the end of the century;

- (2) Pickering E and Bruce B Nuclear Generating Stations to start operating on schedule (eight units between 1983 and 1987);
- (3) A second 500 kV line from Bruce Generating Station to be in-service by 1988;
- (4) Darlington Nuclear Generating Station construction to continue on schedule (four units between 1988 and 1991).

At the request of the Minister of the Environment, Ontario Hydro is also preparing a report on the possible application of some form of Least Emissions Dispatch System (LEDS).

TIME

Low Sulphur Coal

STATUS REPORT ON PROGRAM COMPONENTS

(1) Scrubbers

Preliminary project requirements for sulphur dioxide scrubbers at Lambton or Nanticoke have been issued and the scope of work and budget documents are in preparation.

Four major scrubber suppliers and a major scrubber waste disposal contractor accepted invitations and made presentations describing their products and service to Ontario Hydro staff. A field trip to the Tennessee Valley Authority scrubber installations has been completed.

A review of the experience gained by utilities with the acquisition and installation of scrubbing systems has indicated an earliest practical in-service date of early 1986. This schedule is based on gaining all the necessary environmental approvals to release the tendering documents during February 1982. This schedule would offer the advantage of allowing the final system tie-in and associated unit outages to take place during the summer.

A preliminary review of station selection parameters has indicated a preference for Lambton Generating Station.

A review of sources of lime and limestone within the province has been completed.

(2) Low Nitrogen Oxide Burners

Review of Babcock & Wilcox (B&W) and Combustion Engineering's (CE) retrofit low NO_x burner configurations for Nanticoke, Lakeview and Lambton boilers has been completed.

Funds are being requested to incorporate low NO_x technology on one CE boiler at Lakeview and one B&W boiler at Nanticoke, as a start to the program of NO_x reduction.

(3) Purchases from Other Provinces

A meeting was held with Manitoba Hydro on May 28, 1981 to explore the possibility of purchasing firm power. The purpose of the meeting was related to alternative supply options for Northern Ontario and to the reduction in acid gas emissions.

The basic purchase currently being considered is 200 MW for four years beginning in 1988 at about 60-70% annual capacity factor. It may be possible to advance or extend the delivery schedule to satisfy acid gas emission requirements and this will be discussed as needed in future meetings.

(4) Coal Supply Program

A coal supply program is being developed to meet the currently projected coal requirements up to 1986, consistent with the acid gas emission requirements. Alternative long term energy and fuel supply strategies for the period beyond 1986 are also being developed.

The coal supply program will be reviewed and modified as and when required.

REPORT ON MAJOR FACTORS DETERMINING THE PROGRAM

Since the Acid Gas Control Program is based on a number of determining factors, information is also provided below on each of these factors.

(1) Load Growth

The long-range load forecast of 3.1% average annual load growth for the period 1981-2000 has been adopted for planning purposes in 1981. This long-range forecast is usually reviewed annually and the Acid Gas Control Program will be modified to take into account the revised forecast of load growth and to ensure that the emission regulations will be met.

Currently, the actual energy requirement in the first quarter of 1981 has been less than that designated in Ontario Hydro's latest five year generation projections.

	Forecast GW.h	Actual GW.h	Difference GW.h	%
Primary Demand	28,141	27,821	-320	-1
Secondary Deliveries	<u>3,607¹</u>	<u>3,329</u>	<u>-278</u>	<u>-8</u>
Total	31,748	31,150	-598	-2

¹Forecast Secondary Deliveries include 3411 GW.h of Export Sales and 196 GW.h of Other Deliveries.

(2) Nuclear Program

The advancement of the Darlington Nuclear Generating Station schedule has been approved. The in-service dates are advanced six months for Units 1 and 2 and twelve months for Units 3 and 4 to May 1988, February 1989, November 1989 and August 1990 respectively. While the advancement was justified on economic grounds, the reduction in acid gas emissions was a major additional benefit that was taken into account in the decision making process.

(3) Hydraulic Development Program

Addition of non-fossil generation will displace fossil generation and thereby reduce acid gas emissions. The development of about 1150 MW dependable peak capacity of hydraulic generation between 1987 and 1993 has been reviewed, and is being incorporated in Hydro's future work program. The rivers involved in this program are the Little Jackfish, the Abitibi, the Mattagami and the Moose.

A preliminary scope of work has been issued for studies of two of the developments, totalling about 127 MW dependable peak capacity and 66 Average MW, on the Little Jackfish River. Detailed work programs are being produced by participating departments. Field data on Little Jackfish is being collected as part of the environmental and geotechnical studies.

Studies for the possible development of an additional 850 MW capacity of hydraulic generation by 1995 are being conducted.

(4) Bruce Transmission Line

A report evaluating alternatives for linking Bruce B Nuclear Generating Station to the bulk electricity system and supplying electricity to southwestern Ontario has been issued for public comment and preliminary government review.

An Environmental Assessment will be completed by the end of 1981 and submitted for government review.

The scheduled in-service date for a second 500 kV line from Bruce is 1988. Prior to the installation of this second 500 kV line, the output from the Bruce nuclear complex (maximum of 6200 MW) will be limited to about 4800 MW. During this period, the resulting locked-in nuclear energy required to meet the primary demand will have to be replaced by fossil generation, thereby increasing acid gas emissions.

EXPENDITURES

The present estimated cost of the Acid Gas Control Program is about \$30 million up to 1985 and \$90 million per year thereafter, for a total of about \$500 million for the 1981 to 1990 period. The budget will be further refined as details of specific program components are developed.

In January, the 1981 Work Program budget was increased by \$400,000 to cover the engineering design and studies on scrubbers for two existing 500 MW coal-fired generating units.

PRESENT AND FORECAST ACID GAS EMISSIONS

The January 26, 1981 program announcement was based on the best available information at the end of 1980. Ontario Hydro's emissions in 1981 were then forecast to range from 560,000 to 609,000 tonnes. This was forecast to rise until 1982 as fossil generation met the growth in demand in electricity. New nuclear stations would be commissioned in late 1982 and be in service in 1983. Acid gas emissions were forecast to drop after 1982 to the limits determined by regulation.

The earlier forecasts have been revised. The latest emission forecasts reflect the 1980 station emission rates and the latest five year generation projections. These projections include an annual export of 11,000 GW.h in 1981, 1982 and 1983, 9,000 GW.h in 1984, and 12,000 GW.h in 1985. The projected 1981-1985 emission levels are lower because of lower load growth and higher nuclear availability. The forecast emission levels for 1982 to 1985 are shown in Figure 3.

The 1981 forecast emission level has been further adjusted downward to 480,000 tonnes, taking into account the actual emissions recorded in the first quarter of 1981. The actual generation is compared to the generation projections for these three months in the table which follows:

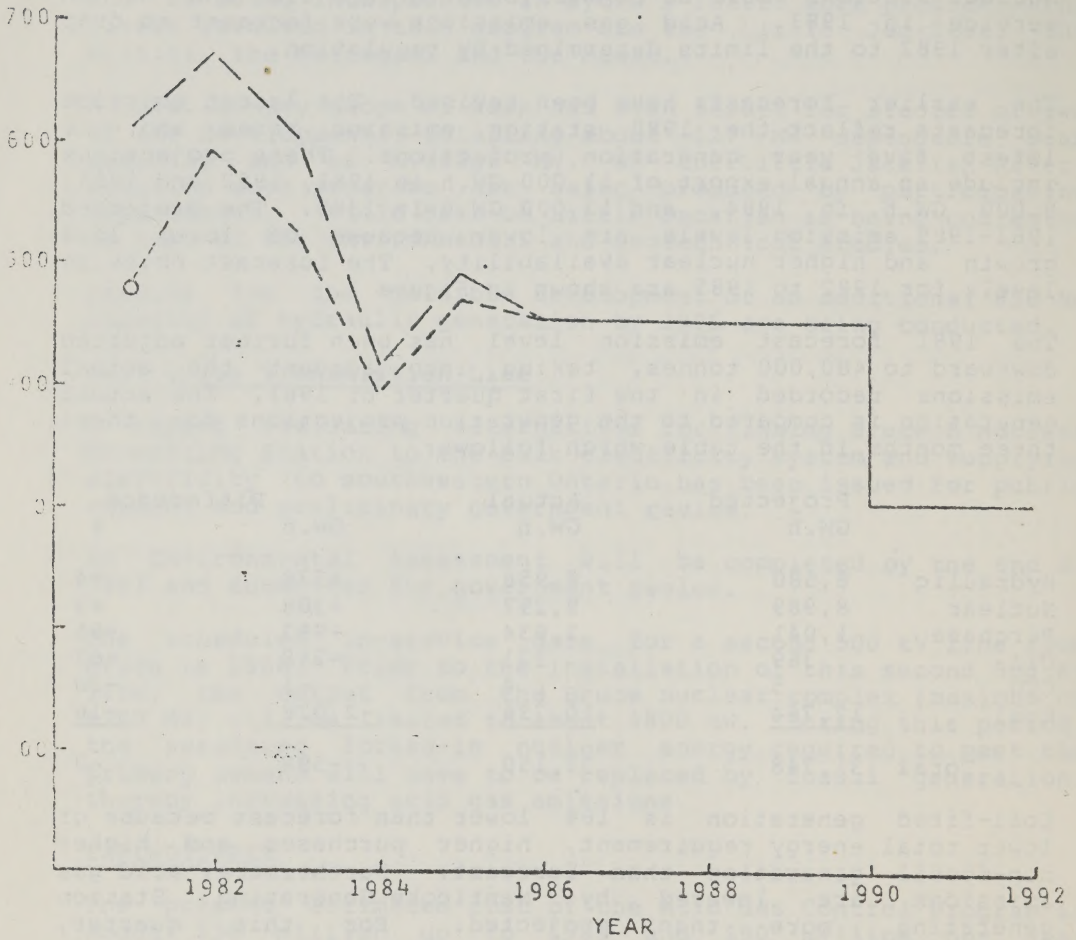
	Projected GW.h	Actual GW.h	Difference GW.h	%
Hydraulic	8,580	8,958	+378	+4
Nuclear	8,989	9,297	+308	+3
Purchase	1,041	2,034	+993	+95
Oil	369	121	-248	-67
CTU	5	4	-1	-20
Coal	12,764	10,736	-2,028	-16
Total	31,748	31,150	-598	-2

Coal-fired generation is 16% lower than forecast because of lower total energy requirement, higher purchases and higher non-fossil generation than forecast. Furthermore, acid gas emissions are lowered by Nanticoke Generating Station generating more than projected. For this quarter, Nanticoke Generating Station burned blended coal with an average sulphur content of 1.31%, compared to the 1980 average of 1.49%.

Reports on actual and latest forecast acid gas emission levels will be provided in subsequent issues of this quarterly status report.

Figure 3

FORECAST ACID GAS EMISSIONS



- Original forecasts of January 1981
- Latest forecasts
- Latest forecast adjusted with actual January-March emissions
- Regulation 73/81 emission limits

